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December 3, 2001

Ms. Magalie Roman Salas
Secretary
Federal Communications Commission
445 Twelfth Street, SW
Washington, DC 20554

Re: Digital Audio Broadcasting Systems and their Impact on the Terrestrial Radio Broadcast Service, MM Docket No. 99-325, RM-9395

Dear Ms. Salas:

The National Association of Broadcasters and the Consumer Electronics Association hereby submit, for inclusion in the above-referenced docket, the attached report of the Evaluation Working Group of the DAB Subcommittee of the National Radio Systems Committee (NRSC) on tests conducted on iBiquity Digital Corporation's FM IBOC system. This report, entitled "Evaluation of the Ibiquity Digital Corporation IBOC System, Part 1 – FM IBOC," was adopted by the NRSC's DAB Subcommittee Evaluation Working Group on November 29, 2001.

Test data on iBiquity's AM IBOC system is expected to be delivered to the DAB Subcommittee in the near future and will then be evaluated by the Evaluation Working Group. The report on the AM IBOC system will be submitted to the Commission upon completion.

Respectfully submitted,

Valerie Schulte

s/ Michael Petricone

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DAB Subcommittee

EVALUATION OF THE IBIQUITY DIGITAL CORPORATION IBOC SYSTEM

Part 1 – FM IBOC

Report from the
Evaluation Working Group
Dr. H. Donald Messer, Chairman

(as adopted by the Subcommittee on November 29, 2001)

Sponsored by the Consumer Electronics Association and the National Association of Broadcasters

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1 INTRODUCTION

This report on the performance and compatibility of the iBiquity Digital Corporation's FM in-band/on-channel (IBOC) digital radio system has been developed by the Evaluation Working Group (EWG, Table 1), Dr. H. Donald Messer, Chairman, of the National Radio Systems Committee's (NRSC's) Digital Audio Broadcasting (DAB) Subcommittee.

Table 1. Evaluation Working Group (EWG) participants†

ORGANIZATION	REPRESENTATIVE
Advanced Television Technology Center	Dr. Charles W. Einolf, Jr., Deputy Executive Director Sean C. Wallace, Systems Engineer
Broadcast Signal Lab	David Maxson
Consumer Electronics Association	Dave Wilson, Director, Engineering
CUE Corporation	Tom Schaffnit, consultant
Denny & Associates	Alan Rosner
Dolby Laboratories	Tim Carroll
Greater Media, Inc.	Milford K. Smith, Vice President, Engineering
iBiquity Digital Corporation	Glynn Walden, Vice President Broadcast Engineering Albert Shuldiner, Esq., Vice President and General Counsel Greg Nease Dr. Ellyn Sheffield
International Association of Audio Information Services (IAAIS)	Dave Andrews, Chief Technology Officer
International Broadcasting Bureau	Dr. H. Donald Messer, Chief, Spectrum Management (Chairman)
Jefferson-Pilot Communications	Tom Giglio, Vice President, Engineering
Journal Broadcast Group	Andy Laird, Vice President, Radio Engineering
National Association of Broadcasters	John Marino, Vice President, Science & Technology David Layer, Director, Advanced Engineering (Secretary)
National Public Radio	Jan Andrews, Senior Engineer
Susquehanna Radio Co.	Charles Morgan, Sr. Vice President
T. Keller Corporation	Tom Keller

† *Additional organizations participated on a less-frequent basis including ABC, Digital Radio Express, Sony, and Wye Consulting*

This work was done in pursuit of the DAB Subcommittee's Goals and Objectives, included in this report as Appendix A. The purpose of this NRSC IBOC evaluation is to determine if the iBiquity FM IBOC system is a significant improvement over the analog systems currently in use, and, to confirm that the impact of the IBOC digital sidebands on existing analog signals is both minimal and acceptable. Note that this report is not itself a standard for IBOC digital radio.

The evaluation effort culminating in this report is the latest in a series of similar evaluations done by the Subcommittee, starting in the 1995-96 timeframe (in conjunction with EIA/CEG, now CEA) on "first generation" IBOC systems,[1] then in 2000 when a "phase 1" evaluation of "next generation" IBOC systems was conducted.[2] This current evaluation effort is the most comprehensive one yet, and is the first

[1] The 1995-96 DAB evaluation with EIA was conducted on four different types of DAB systems—terrestrial new-band (specifically, the Eureka-147 system), satellite (the VOA-JPL S-band system), terrestrial in-band/adjacent channel (IBAC), and terrestrial IBOC (both FM and AM). A detailed report on the test results was published by EIA - see "Consumer Electronics Group, Electronic Industries Association, Digital Audio Radio Laboratory Tests - Transmission Quality Failure Characterization and Analog Compatibility," August 11, 1995.

[2] The NRSC's "phase 1" IBOC evaluation was based on preliminary performance data submitted by Lucent Digital Radio (LDR) and USA Digital Radio (USADR); detailed reports on the results of these evaluations were published by the NRSC – see "DAB

to be based on a full set of FM IBOC system laboratory and field test data collected in strict accordance with NRSC-developed test procedures.

Preparatory work on this report began well in advance of the receipt of test data to be analyzed. The EWG first convened in its present form (and under its present leadership) in March 1999, and met 10 times that year to develop evaluation criteria upon which to judge candidate IBOC DAB systems, as well as an Evaluation Guidelines document[3] which outlined the process by which the EWG would evaluate the data submissions expected from LDR and USADR in December of that year (the so-called "phase 1" evaluation).[4] In the first three months of 2000, the EWG met another 10 times, resulting in the release of two evaluation reports, one each on the LDR and USADR systems.[5]

The NRSC's focus then shifted to development of test procedures for the next phase of the evaluation, resulting in the development of FM and AM IBOC test procedures by the DAB Subcommittee's Test Procedures Working Group (TPWG).[6] The EWG re-convened on May 8, 2001 to begin preparing for receipt of data on iBiquity's FM IBOC system. Between May and August the group reviewed and refined its evaluation criteria based both on the experience gained from the phase 1 evaluation as well as on operational details of the iBiquity FM IBOC technology (*e.g.*, its "blend to analog" feature). Data evaluation began when, on August 8, 2001, a test data report prepared by iBiquity, the Advanced Television Technology Center (ATTC), and Dynastat was delivered to the NRSC ("FM IBOC Test Data Report").[7]

The information contained in the data report was collected by either iBiquity or ATTC in the presence of one or more NRSC observers (Table 2, retained by NAB and CEA), broadcast consulting engineers familiar with both the NRSC's FM IBOC test procedures as well as the underlying technologies and measurement techniques. Subjective evaluations performed on portions of this data were conducted by Dynastat and are documented in the data report, as well. The NRSC observers ensured that the tests were being conducted according to the NRSC's procedures, that the data being recorded (and ultimately submitted to the NRSC) was in fact the data being obtained, and in addition because of their expertise were able to help resolve testing issues as they arose, often in consultation with NAB and CEA staff and the DAB Subcommittee's Test Program Steering Committee.

Table 2. NRSC observers

ORGANIZATION	REPRESENTATIVE(S)	TASKS
Denny & Associates	Alan Rosner, P.E.	Principal field test observer – east coast and midwest
T. Keller Corporation	Tom Keller, President	Principal lab test observer Observer on FM field compatibility tests
Hammett & Edison	Stan Salek, P.E.	Principal field test observer – west coast

All of the conclusions and recommendations which follow in this evaluation report are based upon the information contained in the FM IBOC Test Data Report (including the SCA Test Report), upon information provided to the EWG from the NRSC observers, and upon subsequent analysis of this information. By and large, compatibility with existing analog services and the coverage afforded the new,

Subcommittee – Evaluation of Lucent Digital Radio's Submission to the NRSC DAB Subcommittee of Selected Laboratory and Field Test Results," April 8, 2000, and "DAB Subcommittee – Evaluation of USA Digital Radio's Submission to the NRSC DAB Subcommittee of Selected Laboratory and Field Test Results," April 8, 2000.

[3] See "DAB Subcommittee – In-band/on-channel (IBOC) Digital Audio Broadcasting (DAB) System Evaluation Guidelines," May 25, 1999 (published by the NRSC).

[4] USADR submitted a test report to the NRSC on December 15, 1999; LDR's submission was received on January 24, 2000.

[5] See footnote 2.

[6] The FM IBOC test procedures are included with this report as Appendices B and C.

[7] See Appendix L for a table of contents of this data report. Additional data, on SCA compatibility tests, was submitted to the NRSC by iBiquity and the ATTC on October 19, 2001 (a table of contents for the SCA test report is also included in Appendix L).

digital service were deemed of greater importance to the EWG than were some of the other aspects of IBOC system evaluation such as amount of auxiliary data capacity. This evaluation report is solely a technical evaluation and does not address costs of transition nor the costs of receiver implementation.

1.1 Test parameters

Detailed laboratory and field test procedures were developed by the DAB Subcommittee and are included with this report as Appendices B and C, respectively (these are discussed in greater detail in Section 3). These tests were conducted on the "baseline" iBiquity FM IBOC system (Table 3), commonly referred to as the "hybrid" mode of operation, generally recognized to be more technically challenging to implement than is the all-digital mode.[8] In addition, the hybrid mode represents the first step in the transition from analog to digital radio broadcasting and as such there is an immediate need to characterize its behavior.

Table 3. iBiquity FM IBOC system – baseline parameters

PARAMETER	VALUE
Main channel digital audio bit rate	96 kbps
IBOC digital sideband bandwidth (per side)	69 kHz (service mode MP1)[9]
IBOC digital sideband power level (total, with respect to total analog power level)	-20 dB
Auxiliary data rate	3-4 kbps (1 kbps dedicated; 2-3 kbps opportunistic)

1.2 Future work

There are two important IBOC-related tasks still facing the NRSC. Most immediately, an evaluation of iBiquity's AM IBOC system needs to be undertaken; this will commence as soon as the AM IBOC test data is released to the NRSC (this data is expected in December 2001), and will be reported as Part 2 of this report.

All of the test results analyzed in this report were obtained on a version of the iBiquity FM IBOC system implemented with MPEG-2 AAC perceptual audio coding. Since iBiquity has stated it intends to release its system commercially with their own proprietary audio coding technology (based on PAC, developed by Lucent Technologies), they have agreed to provide the NRSC with data on a system based on their own proprietary audio coding technology when available.

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[8] See IBOC FM Test Data Report, Appendix A, for information on the various modes of operation.

[9] See IBOC FM Test Data Report, Appendix A, pg. 19, for a precise spectral occupancy description of this service mode.

2 CONCLUSIONS and RECOMMENDATIONS

Based on careful evaluation of the test data, the NRSC has concluded that the performance of the iBiquity FM IBOC system as tested represents a significant improvement over today's existing analog services. The impact of IBOC digital sidebands on the performance of existing main channel audio services is varied: listeners should not perceive an impact on the analog host signal, nor on the analog signals on carriers that are either co-channel or 2nd-adjacent channel with respect to an IBOC signal. With respect to carriers that are located 1st-adjacent to an IBOC signal, listeners within the protected contour should not perceive an impact, but a limited number of listeners may perceive an impact outside of the protected contour under certain conditions.

So, after nearly a decade of encouraging the development of IBOC DAB and now culminating with the formulation and execution of a comprehensive test program, the NRSC believes that the iBiquity FM IBOC system as tested will offer FM broadcasters significantly enhanced performance over that which is presently available from traditional analog FM broadcasting. The enhancements include almost full immunity from typical FM multipath reception problems, significantly improved full-stereo coverage, flexible data casting opportunities, and an efficient means for FM broadcasters to begin the transition to digital broadcasting.

The NRSC also believes that the tradeoffs necessary for the adoption of FM IBOC are relatively minor. With respect to the main channel audio signal, evaluation of test data shows that a small decrease in audio signal-to-noise ratio will be evident to some listeners in localized areas where 1st-adjacent stations, operating with the FM IBOC system, overlap the coverage of a desired station. However, listeners in these particular areas may also be subject to adjacent-channel *analog* interference which will tend to mask the IBOC-related interference, most appropriately characterized as band-limited "white" noise, rendering it inaudible under normal listening conditions. Also, all present-day mobile receivers include a stereo blend-to-mono function dynamically active under conditions of varying signal strength and adjacent channel interference. This characteristic of mobile receivers will also tend to mask any IBOC-related noise. The validity and effectiveness of these masking mechanisms is apparent from the rigorous subjective evaluations performed on the data obtained during the NRSC's adjacent-channel testing.

Extensive laboratory and field tests supervised by the NRSC and performed on this IBOC system show the feasibility of the iBiquity technology. Furthermore, the system as tested by the NRSC provides an extremely smooth and acceptable transition from digital to analog in areas of weak signal strength, offering broadcasters robust digital coverage for a new generation of digital receivers with no significant loss in existing analog coverage areas.

The NRSC therefore recommends that the iBiquity FM IBOC system as tested by the NRSC should be authorized by the FCC as an enhancement to FM broadcasting in the U.S., charting the course for an efficient transition to digital broadcasting with minimal impact on existing analog FM reception and no new spectrum requirements.

2.1 Digital performance

Given here are the NRSC's findings for each of the eight digital performance evaluation criteria. Each of these findings is elaborated on in Section 4 below:

Audio quality

The iBiquity hybrid FM IBOC system with MPEG-2 AAC perceptual audio coding demonstrates significantly improved audio quality compared to existing analog FM in mobile listening environments. Since the final version of this system will utilize a proprietary iBiquity perceptual audio coding algorithm and not MPEG-2 AAC, no direct findings on the unimpaired audio quality of the final system can be made at this time.

Service area

NRSC test results indicate that hybrid FM IBOC digital coverage is comparable to analog coverage along radial and loop routes tested. Due to FM IBOC's improved resistance to various types of interference (co- and adjacent channel, impulse noise, and multipath fading in particular), FM IBOC service may be obtained in areas where analog service is currently of unacceptable quality due to such interference.

Durability

NRSC test results demonstrate that the iBiquity hybrid FM IBOC system, compared to analog FM, is substantially more robust to impulse noise, co- and adjacent channel interference, and multipath fading.

Acquisition performance

The acquisition performance of the iBiquity hybrid FM IBOC system is identical to that of an analog FM radio since, by design, an IBOC receiver initially acquires using the analog portion of the hybrid FM IBOC signal.

Auxiliary data capacity

The iBiquity hybrid FM IBOC system design incorporates an auxiliary data transmission feature with a minimum capacity of 3-4 kbps. This system feature was not tested by the NRSC.

Behavior as signal degrades

NRSC testing has demonstrated that the iBiquity prototype hybrid FM IBOC receiver's audio during the blend process is perceived to have the same quality as does the analog audio, and, that the blend process itself does not degrade the IBOC receiver's audio quality below that of analog.

Stereo separation

FM IBOC receivers are expected to exhibit superior stereo separation compared to analog automotive FM receivers due to the fact that the FM IBOC receiver should be receiving digital stereo audio under circumstances for which an analog automotive FM receiver would be blending to mono.

Flexibility

There are a significant number of features in the iBiquity FM IBOC system which should provide for system flexibility and should offer broadcasters and receiver manufacturers opportunities to customize services and equipment for their particular goals, and offer the possibility of performance improvements in the future. None of these features were tested by the NRSC.

2.2 Analog compatibility

Given here are the NRSC's findings for both of the compatibility evaluation criteria. Each of these findings is elaborated on in Section 4 below:

Host analog signal impact

NRSC tests indicate that listeners should not perceive an impact on analog host reception due to hybrid FM IBOC operation.

Non-host analog signal impact

For the three cases considered, the following findings apply regarding the introduction of hybrid FM IBOC into the FM band:

Co-channel interference: no impact on analog reception (by design).

1st-adjacent channel interference: listeners within the protected contour should not perceive an impact, but a limited number of listeners may perceive an impact outside of the protected contour under certain conditions.

2nd-adjacent channel interference: NRSC tests indicated that some receivers (with performance similar to the NRSC analog automotive and portable receivers) should not experience an impact on performance due to 2nd-adjacent channel hybrid FM IBOC interference, however, a very limited number of receivers (with performance similar to the home hi-fi receiver used in the NRSC tests) might experience a negative impact for -30 to -40 dB (and more negative) D/U ratios.

Impact on SCA reception

Careful evaluation of test data shows that the digital SCA services tested (RDS and DARC) should not be adversely impacted by IBOC. For the case of analog SCA services, some questions still remain as to the impact of IBOC on such services. In order to answer these questions and to provide additional clarity to this matter, iBiquity, National Public Radio and the International Association of Audio Information Services have agreed to expeditiously perform a series of additional tests for the purpose of determining how certain SCA receivers will perform after IBOC is implemented on host and adjacent channel stations. The NRSC encourages the rapid completion of these tests in time to provide meaningful input to the FCC for its consideration.

2.3 "Baseline" mode of operation

The NRSC has only studied operation of this system using the baseline parameters (Table 3 above). The conclusions and recommendations in this report apply to that mode of operation only.

3 NRSC TEST PROGRAM

In this section, background information on the NRSC's FM IBOC test program is provided, including some of the basic attributes of the iBiquity FM IBOC system which were taken into account as the NRSC test procedures (Appendices B and C to this report) were developed.

To evaluate an IBOC radio system, two basic types of tests are required (done in both the laboratory and the field), both of which are found in the NRSC's IBOC test procedures:

- Performance tests: in the context of the NRSC's test procedures and evaluation reports, "performance tests" (sometimes called "digital performance tests") are those used to establish the performance of the IBOC digital radio system itself. Performance test results are obtained using an IBOC receiver or through direct observation of the received signal.
- Compatibility tests: again, in the context of the NRSC's IBOC evaluation, "compatibility tests" (sometimes referred to as "analog compatibility tests") are designed to determine the effect that the IBOC digital radio signal has on existing analog signals (main channel audio and subcarriers). Compatibility testing involves observing performance with IBOC digital sidebands alternately turned on and off; test results are obtained using either analog FM receivers or FM subcarrier receivers (analog or digital) or through direct observation of the received signal.

For each of these, two basic types of measurements are made:

- Objective measurements: where a parameter such as signal power, signal to noise ratio, or error rate is measured, typically by using test equipment designed specifically for that particular measurement (*e.g.*, power meter, error rate test set).
- Subjective measurements: involve human interpretation or opinion – not something that can be simply measured with a device. In the NRSC test program, subjective measurements involve determining the quality of audio recordings by having people listen to them and rate them according to a pre-defined quality scale.

Subjective evaluation is especially important when trying to assess the quality of IBOC digital audio since the IBOC radio system relies upon perceptual audio coding for audio transmission. The listening experience of audio which has passed through a perceptually coded system is not best characterized by many of the normal objective audio quality measures such as signal-to-noise, distortion, or bandwidth. The instruments used to make such measurements do not adequately respond to the perceptual aspects of the system. This is one of the reasons why the NRSC's test program includes such a comprehensive subjective evaluation component.[10]

3.1 *iBiquity FM IBOC system*

The iBiquity FM IBOC system supports transmission of digital audio and auxiliary digital data within an existing FM channel allocation by placing two groups of digitally modulated carrier signals adjacent to an analog FM signal as shown in Figure 1. These sideband groups are independent in that only one group (either USB or LSB in the figure) is needed for an IBOC receiver to be able to generate digital audio. Orthogonal frequency division multiplexing ("OFDM") modulation is utilized. The digital audio modulated onto these OFDM carriers is perceptually coded, allowing for high-quality digital audio using a relatively low bit rate (96 kbps was the digital audio bit rate used for the NRSC tests).

[10] See IBOC FM Test Data Report, Appendix H, for a detailed description of the subjective testing methodology used in the NRSC's test program.

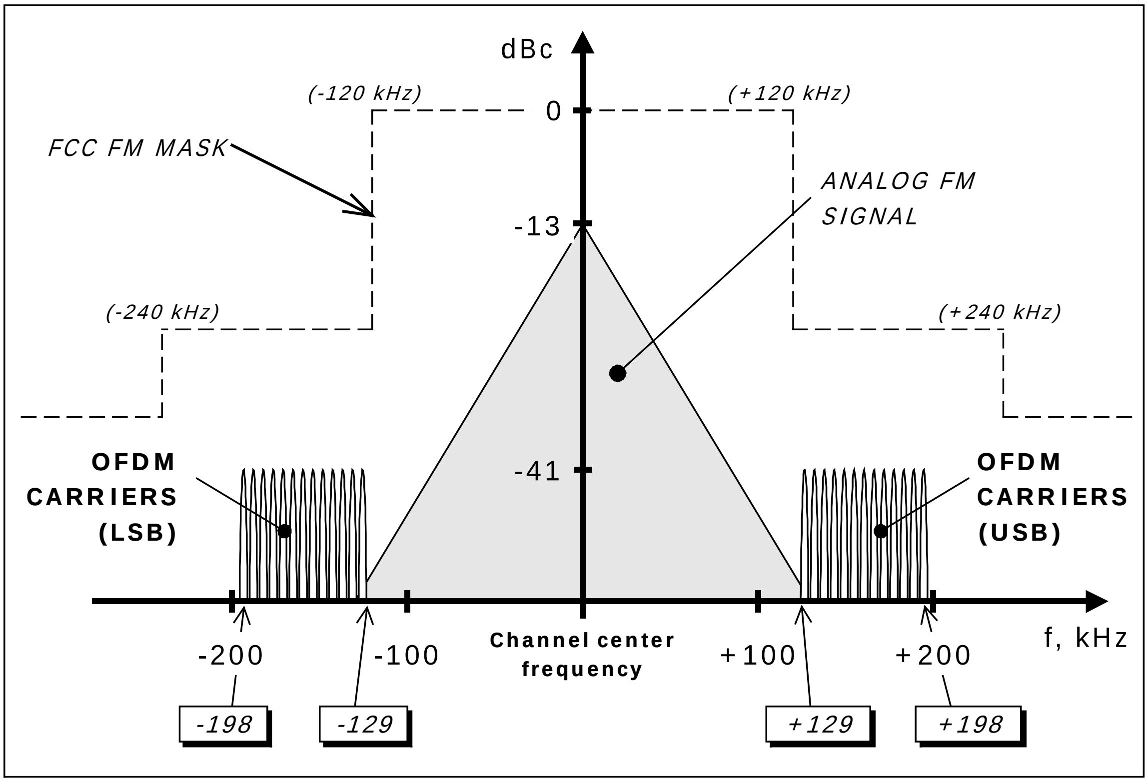

Figure 1. iBiquity FM IBOC system signal spectral power density

A complete description of the FM IBOC signal is given in the IBOC FM Test Data Report.[11] This system incorporates a 4 1/2 second delay between the analog and digital (simulcast) audio signals to improve performance in the presence of certain types of interference, which may affect how broadcasters monitor off-air signals.[12] Some of the specific attributes of this system which influenced the design of the NRSC's test program are listed here:

- Proximity of digital sidebands to 1st-adjacent channel signals: the digital sidebands of the FM IBOC signal are located such that they could potentially interfere with (and receive interference from) a 1st-adjacent analog FM signal (Figure 2). The NRSC test procedures include tests which characterize this behavior, including tests of IBOC performance when there are two 1st-adjacent channel signals, one on either side of the desired signal (hence both digital sidebands are experiencing interference).

[11] See IBOC FM Test Data Report, Appendix A ("IBOC FM Transmission Specification").
[12] For additional information on this see IBOC FM Test Data Report, Appendix A, pg. 4.

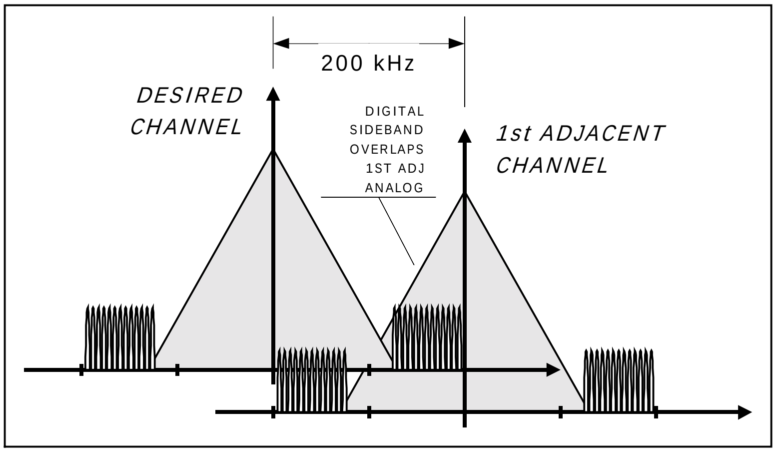

Figure 2. Illustration of potential interference to/from 1st-adjacent analog signals by FM IBOC digital sidebands

- Proximity of digital sidebands to 2nd-adjacent channel signals: the FM IBOC system design allows for approximately 4 kHz of "guard band" between 2nd-adjacent IBOC digital sidebands (Figure 3). Because this relatively close proximity could have an impact on performance, the NRSC test procedures include tests for characterizing performance with 2nd-adjacent interference, including dual 2nd-adjacent channel interferers with power levels up to 40 dB greater than the desired signal power (since FCC rules allow a 2nd-adjacent signal to be 40 dB stronger than the desired signal at the desired signal's protected contour).

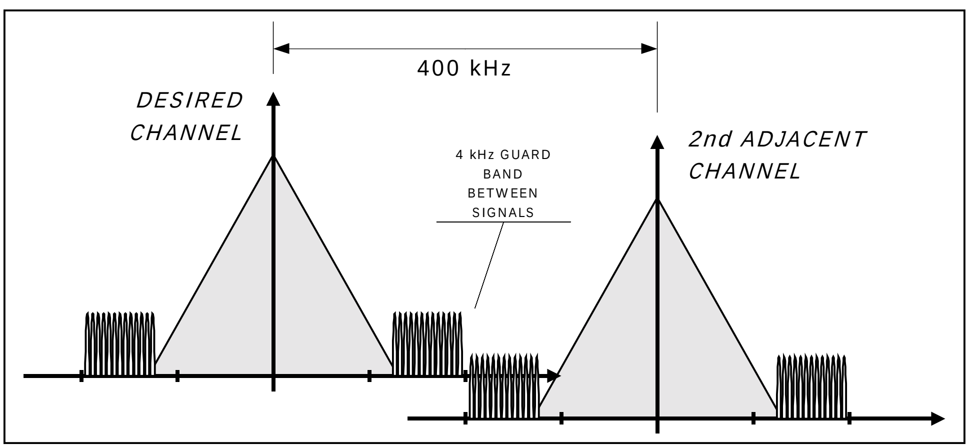

Figure 3. Illustration of potential interference between 2nd-adjacent FM IBOC signals

- Blend-to-analog: the iBiquity FM IBOC system simulcasts a radio station's main channel audio signal using the analog FM carrier and IBOC digital sidebands, and under certain circumstances, the IBOC receiver will "blend" back and forth between these two signals. Consequently, depending upon the reception environment, the listener will either hear digital audio (transported over the IBOC digital sidebands) or analog audio (delivered on the FM-modulated analog carrier), with the digital audio being the primary condition.

  The two main circumstances under which an IBOC receiver reverts to analog audio output are during acquisition i.e. when a radio station is first tuned in (an IBOC receiver acquires the analog signal in milliseconds but takes a few seconds to begin decoding the audio on the digital sidebands), or, when reception conditions deteriorate to the point where approximately 10% of the data blocks sent in the digital sidebands are corrupted during transmission. Many of the tests in the NRSC procedures are designed to determine the conditions which cause blend-to-analog to occur in this second circumstance, since at this point the IBOC system essentially reverts to analog FM.

iBiquity has indicated that the analog section of the prototype IBOC receiver used for the NRSC tests is a "software radio" and has not yet been optimized to the point where it performs commensurate with existing analog radios (automotive radios in particular). Consequently, the NRSC elected not to do any evaluations on the IBOC receiver output after it had blended to analog, but instead, would evaluate the output of an existing analog receiver operating under the same signal conditions as those which resulted in blend-to-analog in the IBOC receiver, when such evaluation was required. Typically, tests specify recording of the IBOC receiver output just before (with respect to the test conditions) it blends to analog, guaranteeing that it will be operating in digital audio mode, and recording of the audio from an existing analog receiver under identical conditions, then these recordings are subjectively evaluated so that digital and analog receiver performance near the (IBOC receiver) point of blend-to-analog can be compared.

3.2 Lab tests

Laboratory tests are fundamental to any characterization of a new broadcast system such as FM IBOC. The controlled and repeatable environment of a laboratory makes it possible to determine how the system behaves with respect to individual factors such as presence or absence of RF noise, multipath interference, or co- and adjacent-channel signals. These factors all exist in the "real world" but because they exist simultaneously and are constantly changing, it is virtually impossible to determine, in the "real world," the effect each has on system operation.

For the NRSC test program, an independent testing facility—the Advanced Television Technology Center (ATTC)—was selected to conduct all laboratory tests. Prior to testing, the ATTC developed and carried out a test bed "proof of performance" plan, and submitted the results of this proof to the NRSC.[13] As discussed above in Section 1, NRSC observers were present for the vast majority of all lab tests conducted at ATTC. The ATTC was also involved in preparing the recorded audio cuts for the subjective evaluation which was done by another independent testing contractor, Dynastat, Inc.

3.3 Field tests

Field testing of a new broadcast system is necessary to determine performance in "the real world" where all of the various factors which impact propagation and reception of radio signals exist to varying degrees depending upon time of day, geographic location and environmental factors. For the NRSC test program, eight FM stations were selected for use in field testing (Table 4).

[13] See "Digital Audio Broadcasting – Test Bed Proof-of-performance Plan," ATTC doc. no. 00-05, December 2000, rev. 1.1, and "Digital Audio Broadcasting – Test Bed Proof-of-performance," ATTC doc. no. 01-01, January 2001, rev. 1.0.

Table 4. FM IBOC field test stations

STATION	FORMAT	LOCATION	PRINCIPLE TEST CONDITION(S) †	COMMENTS
WETA 90.9	Talk and classical	Washington, D.C.	(a) low interference and low multipath	• Chan. 215B - # of radials - 8 • Host compatibility
WPOC 93.1	Country	Baltimore, MD	(c) single first adjacent interferer	• Chan. 226B - # of radials - 5 • Host, 1st-adj. compatibility (WMMR, WFLS)
WD2XAB 93.5	Test	Columbia, MD	(d) single second adjacent interferer	• Chan. 228A – limited testing • 2nd-adj. tests (WPOC is 2nd-adj. IBOC interferer)
KLLC 97.3	"Alice" (contem-porary rock)	San Francisco, CA	(b) low interference, moderate/strong multipath (f) terrain obstructions	• Chan. 247B - # of test loops – 5 • EIA/NRSC test routes used (from 1996 tests) – routes are loops (not radials)
WHFS 99.1	Rock	Annapolis, MD	(e) simultaneous dual interferers, to the extent feasible	• Chan 256B - # of radials – 1 (towards 2nd-adj's) • Two strong 2nd-adj. interferers (WMZQ, WJMO)
KWNR 95.5	Country	Las Vegas, NV	(b) low interference, moderate/strong multipath (f) terrain obstructions	• Chan 238C - # of radials - 8 • "Specular" multipath (Las Vegas "Strip")
WNEW 102.7	Talk and Rock	New York, NY	(b) low interference, moderate/strong multipath (g) centrally-located urban antenna (h) combined antenna (i) strong single 1st adjacent interferer	• Chan. 274B # of radials – 4 (also "urban circles") • 1st-adj. compatibility (WMGK) • "Specular" multipath (downtown NYC) • Antenna located on top of Empire State Building
WWIN 95.9	Urban (pop)	Baltimore, MD	(d) single second adjacent interferer (j) low power combiner/common amp. (k) class A FM facility	• Chan 240A - # of radials – 4 • Only station to use low power combiner (other stations all use high-power combiner)

†*letters in parentheses refer to test condition designations used in FM field test procedures.*

Data collection in the field was done using test vehicles provided by iBiquity Digital Corporation (one such vehicle is shown in Figure 4 and Figure 5). These vehicles were outfitted with an array of test equipment and computers, and utilized four analog FM receivers (see Table 6) and an iBiquity FM IBOC prototype receiver for capturing analog and IBOC radio transmissions, respectively.

Figure 4. Field test vehicle (provided by iBiquity Digital Corporation)

Figure 5. Interior view of field test vehicle showing analog and IBOC receivers, computer, and test equipment

NRSC field test observers were present during collection of all field test data, which was collected principally with the test vehicle in motion, although most of the analog compatibility measurements done in the field were done with the test vehicle stationary. NRSC observers also participated in the preparation of audio cuts obtained in the field for subjective evaluation. As was true for the laboratory tests, an independent test contractor, Dynastat, Inc., conducted the subjective evaluations.

3.4 Analog FM receivers

Four commercially-available analog FM receivers were used for compatibility testing of main channel audio services (see Table 6 below). These receivers were chosen to be representative of the vast majority of receivers used in the U.S. In December, 2000, CEA's Market Research Department provided the NRSC with the names of three of the top five brands, listed alphabetically, for each of three general receiver categories (Table 5), indicating that any model of radio from one of the brands indicated in Table 5 would represent one of the top-selling models in the U.S. in December, 2000.

Table 5. CEA AM/FM receiver market research results – December 2000

RECEIVER TYPE	3 OF TOP 5 BRANDS
Home (hi-fi)	Pioneer, Sony, Technics
CD boom box	Aiwa, Philips, Sony
Auto aftermarket CD	Kenwood, Pioneer, Sony

To determine if a single radio from each category would be sufficient to predict the performance of all radios in that category, advice was sought from Mr. Jon Grosjean, an expert on radio receivers who frequently provides consulting services to radio receiver manufacturers. According to Mr. Grosjean, the tuning circuitry inside modern FM radios generally falls into three categories that are defined by selectivity, specifically: "moderately selective" receivers, "selective" receivers, and "very selective" receivers. Mr. Grosjean said that clock, personal, and portable radios marketed in the U.S. are generally moderately selective, and as a result are least adept at rejecting adjacent channel interference.

Regarding home stereo receivers, Mr. Grosjean said these are generally selective and are good at rejecting adjacent channel interference, though he noted there may be a few inexpensive home stereo receivers on the market that are only moderately selective, and there may be a few very expensive home stereo receivers on the market that are very selective, though these would be the exception for this category. And for automotive radios, Mr. Grosjean indicated these are generally very selective, though there may be some models on the market that are simply selective. Generally speaking, Mr. Grosjean felt that OEM radios are usually the most selective, though aftermarket radios appear to have shown a tendency towards greater selectivity in recent years.

In light of the CEA receiver market data, and Mr. Grosjean's insights into receiver design, the NRSC selected the receivers listed in Table 6 for compatibility testing. The Pioneer, Sony and Technics receivers were available in Washington, DC area retail stores in December, 2000, and the Delphi OEM receiver was being installed in automobiles in December, 2000. All four were examined by Mr. Grosjean. They were also examined by Mr. Robert McCutcheon, who has performed extensive radio receiver tests for the NRSC in the past.[14] Both Mr. Grosjean and Mr. McCutcheon confirmed that these radios were representative of their respective categories.

Table 6. Analog FM receivers used in the NRSC test program

MANUFACTURER	MODEL NO.	TYPE	COMMENTS
Delphi	09394139	OEM automotive receiver	Very selective
Pioneer	KEH-1900	Aftermarket automotive receiver	Very selective
Sony	CFD-22S	Portable radio	Moderately selective
Technics	SA-EX140	Home stereo receiver	Selective

3.5 Analog subcarrier receivers

In the fall of 2000, the Test Procedures Working Group (TPWG) of the NRSC's DAB Subcommittee needed to select a limited number of 67 kHz and 92 kHz analog SCA receivers for use in the NRSC FM IBOC test program. One of the group's members, the International Association of Audio Information Services (IAAIS), Mr. Dave Andrews, representative, offered to study this matter and make recommendations in this area. This offer was appreciated by the TPWG since IAAIS represents individuals who are major users of the SCA receivers in question.

Using the IAAIS-operated, Internet-based listserv, Mr. Andrews conducted an informal survey of IAAIS members to determine which receivers (make and model, and SCA frequency, in particular) were used and in what numbers. He was then able to rank the receivers according to frequency of use and selected the four units most commonly used (Table 7) which are the receivers the NRSC ultimately selected.

Table 7. Analog SCA receivers used in the NRSC test program

MANUFACTURER	MODEL NO.	SUBCARRIER FREQUENCY
McMartin	TRE5	67 kHz
Norver	Nu-1C	67 kHz
CozmoCom	HL922	92 kHz
Compol	SCA-BL	92 kHz

Of the four receivers listed in Table 7, two are no longer manufactured, but are still in the field in large numbers. These are the McMartin and the Norver units. The second two receivers, the CozmoCom and the Compol are widely used by radio reading services and both companies are still active in the field. Furthermore, the CozmoCom unit is also widely used by listeners of ethnic SCA broadcast services.

3.6 Digital subcarrier receivers

The EWG elected to perform compatibility tests on two types of digital subcarriers: Radio Data System (RDS) subcarriers, standardized for North American broadcasters under the NRSC's RBDS

[14] See Appendix D for data resulting from Mr. McCutcheon's examination.

Standard,[15] and the DAta Radio Channel (DARC) subcarrier, developed by NHK of Japan and used worldwide, most notably in the U.S. by CUE Corporation. For the RDS tests, an Audemat integrated RDS receiver was used; for DARC, a Sectra DRB-3000 DARC receiver was used. These receivers were selected primarily because the software used to support them would allow for observation and recording of the block error rate (BLER) performance of the receivers during operation, the principal benchmark of performance used for the NRSC's digital subcarrier receiver tests.

[15] See "United States RBDS Standard," April, 1998 (published by the NRSC).

4 DISCUSSION OF FINDINGS

In this section a detailed explanation of the EWG's review of test data submitted to the NRSC will be presented. References are made throughout to specific test results from the FM IBOC Test Data Report, in particular in summary tables (*e.g.*, Table 10) given at the beginning of many of the sub-sections below. In these tables, references to page numbers, appendices, figures, tables, and so forth, are taken from the FM IBOC Test Data Report, and are provided here to identify specific test results that the EWG used during its evaluation. The findings presented here, and for that matter every aspect of the NRSC's IBOC test program, have been divided into two specific areas - *digital performance* and *analog compatibility*.

4.1 Digital performance

Digital performance refers to the performance of the IBOC digital radio system itself. As discussed below in Section 4.3, eight specific areas of digital performance have been considered by the EWG. All of the test results obtained on digital performance were obtained using an iBiquity prototype IBOC receiver (Figure 6) or through direct observation of the received signal. At least three examples of the iBiquity IBOC receiver were used during testing – one each in two separate field test vehicles, and one in the laboratory.

Figure 6. iBiquity prototype receiver –as used in field test vehicle (receiver is rectangular black box in upper right-hand corner of rack)

In evaluating the digital performance of the system, the EWG's task was to determine if the digital performance demonstrated by the test results was a "significant improvement over existing analog services," as directed by the Subcommittee's Goals and Objectives statement. Guiding the EWG as it attempted to determine this was a set of performance goals it developed (Table 8) defining in more concrete terms what a "significant improvement over existing analog services" consists of.

Table 8. FM IBOC performance goals as established by the EWG

CATEGORY		PERFORMANCE GOALS – FM IBOC
Fidelity	Frequency response & distortion	Frequency response & distortion fidelity should be comparable to or better than the best FM
		To alleviate the effects of channel impairments and interference, it may be acceptable to diminish distortion and frequency response fidelity to maintain audio free of dropouts and noticeable artifacts.
	Noise	May be acceptable to compromise noise fidelity to maintain dropout- and artifact-free audio
	Stereo separation	May be acceptable to compromise in response to channel impairments
	Fidelity of digital technologies	a) Source coding should not cause artifacts that noticeably reduce fidelity throughout the service area b) Should have sufficient apparent dynamic range so that low level and dynamic content reproduce with the same fidelity as aggressively processed audio
Durability	Interference	Digital systems should reach a service area that matches or exceeds actual interference-limited service area of the analog host
	Impairments	Digital technology will be considered to be better than analog against impairments if digital multipath and fade artifacts have the following characteristics: a) They are demonstrably less objectionable, less frequent in time and less prevalent in location than those of analog services b) They maintain higher fidelity than analog for a preponderance of occurrences c) They result in fewer total losses of intelligible audio than analog, and recovery from total loss is not significantly longer than analog in similar circumstances
Flexibility	Flexibility of transmission systems *(includes COMPATIBILITY with existing analog services)*	A successful digital technology will: a) Reasonably protect the performance and flexibility of its analog host and adjacent channel stations (i.e. is compatible with existing analog services); b) Provide a platform that can be improved in software, firmware and hardware in a manner that is compatible with its original technology; c) Give broadcasters tools to create features to enhance the listener experience and permit the medium to remain relevant and competitive in the coming decades.

In anticipation of the need for a comparison between analog and digital performance, the NRSC's test procedures in most cases require the collection of analog data (using existing analog FM receivers) and hybrid IBOC data (using the iBiquity prototype IBOC receiver) either simultaneously (utilizing the IBOC host as the analog signal) or sequentially (for example, in the laboratory), such that a valid comparison could be made. Figure 7 offers a perfect example of how this approach can lead to a meaningful comparison of IBOC and analog from which conclusions about digital performance can be drawn.

In this figure, the subjective evaluation scores[16] of audio samples collected in the field, for both FM IBOC and analog, have been plotted by program type illustrating the differences perceived by listeners between digital and analog performance. Note that the analog and digital audio cuts evaluated were obtained simultaneously under identical reception conditions (four and one-half second time delay between analog and digital notwithstanding)—this is possible since the transmitted audio is simulcast on the IBOC and analog signals—and that consequently this data offers an excellent opportunity to fairly and accurately compare digital and analog performance. Referring to the figure, the data indicate that while the analog quality is in the "fair" range, the IBOC quality is in the "good" to "excellent" range, representing a very significant difference between the two. Clearly, this data suggests that for all program types tested, the digital performance was a consistent and significant improvement over the analog.

[16]The evaluation scores are expressed in terms of Mean Opinion Score ("MOS"), a rating of audio quality. For these tests, the MOS scale used was 5=Excellent, 4=Good, 3=Fair, 2=Poor, 1=Bad. Additional information on the subjective evaluation methods used in this evaluation may be found in Appendix H of the FM IBOC Test Data Report.

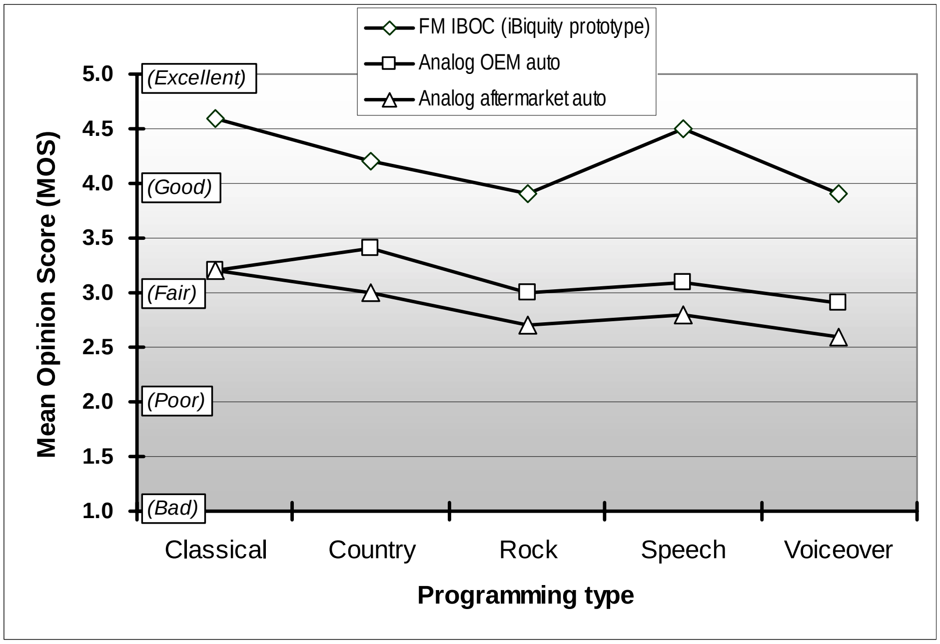

Figure 7. Comparison of FM IBOC and analog audio subjective evaluation results aggregating all field test conditions[17]

Another good example of how the EWG was able to compare digital and analog performance is shown in Figure 8, taken from Appendix K of the FM IBOC Test Data Report, the so-called "ticker test" (discussed more fully below in Section 4.5.8). These results are also subjective in nature, and compare the number of "impairments" (ticks, pops, clicks, etc.) heard by listeners on field test audio obtained simultaneously on an IBOC and on two automotive analog FM receivers (the same receivers for which data was presented in Figure 7). As discussed above for Figure 7, because the digital and analog audio recordings were made simultaneously under identical reception conditions (four and one-half second time delay between analog and digital notwithstanding), the results are directly comparable, and again, there is strong evidence that the digital performance is a significant improvement over the performance offered by analog FM, since so many fewer impairments were heard in the IBOC signal.

[17] Taken from pg. 9 of main text of iBiquity Digital Corporation report to the NRSC, August 2001, with minor modification.

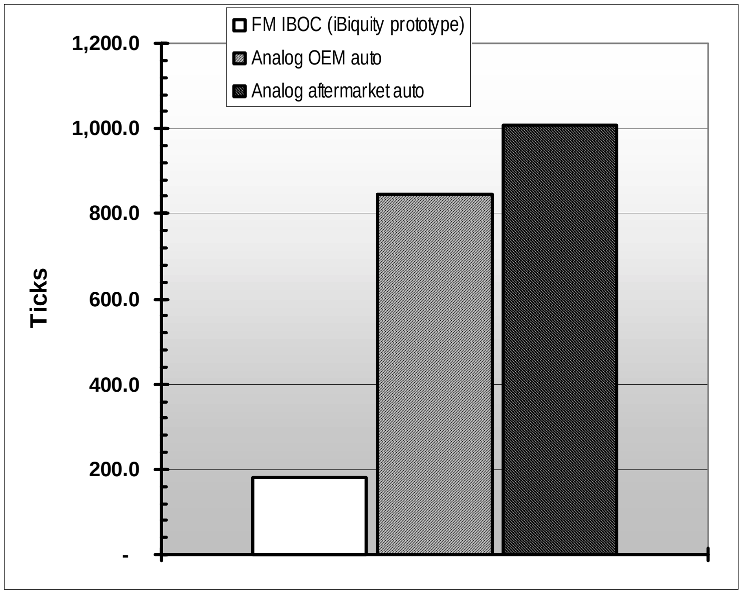

Figure 8. Comparison of FM IBOC and analog (automotive) receivers using "ticker" test - each "tick" corresponds to an audio impairment heard by a listener

4.2 Analog compatibility

The other area of investigation undertaken by the EWG is that of *analog compatibility*. Analog compatibility pertains to the effect that the IBOC digital radio signal has on reception of existing analog signals (both main channel audio and subcarriers). Because of the fact that an FM IBOC signal adds additional energy within a radio station's existing frequency allocation (see Figure 1 above) it is reasonable to expect that analog receivers, not designed with this extra signal energy in mind, may experience interference from this additional energy. The role of the NRSC here is to confirm that IBOC has either no impact or an "acceptable" impact on how existing analog signals are received.

Whether or not interference will exist depends on a variety of factors, one of the most important being the signal level of the IBOC digital sidebands with respect to the host analog signal. This is a critical parameter—the sideband level must be set high enough to provide for good digital coverage, but low enough so that the impact on analog signals is minimized—and is in fact one of the most difficult tradeoffs that IBOC system designers have to deal with.

There are three general types of compatibility – host, first adjacent channel, and second adjacent channel. Host compatibility relates to the impact the IBOC system has on analog reception of the station the IBOC system is installed on. 1st-adjacent channel compatibility relates to the impact the IBOC system has on analog reception of a station located 200 kHz above (or below) the station broadcasting the IBOC signal (see Figure 2 above). Similarly, 2nd-adjacent channel compatibility relates to the impact the IBOC system has on analog reception of a station located 400 kHz above (or below) the station broadcasting the analog signal (see Figure 3 above). Two examples of compatibility as measured in the field under this test program are provided in Figure 9 and Figure 10, for host and 1st adjacent channel compatibility, respectively.

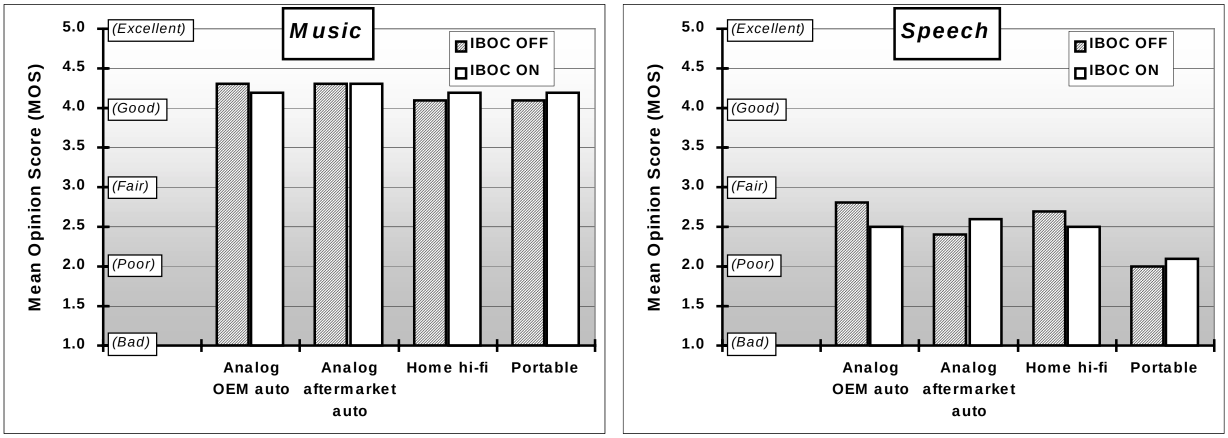

Figure 9. Host compatibility – subjective evaluation results of audio recordings obtained in the field

As in Figure 7 above, these figures present subjective evaluation results obtained on field test recordings of the main channel audio signal. For each figure, results are presented for some or all of the analog receivers used in NRSC testing. For each set of test parameters (e.g., program type, amount of interference) note how the receivers perform differently from one another under identical test conditions, illustrating one reason why it was important for the NRSC to carefully select the analog receivers (as discussed in Section 3.4 above). In
Figure 9, it is also interesting to note that the perceived audio quality, whether or not the IBOC sidebands are present, is highly dependent upon the type of programming being listened to. Specifically, "music" programming rated much higher (in the "good" range) than did "speech" programming (in the "poor" to "fair" range), under similar conditions. Overall, the small differences between "IBOC on" and "IBOC off" in Figure 9 indicate that the impact of the IBOC digital sidebands on the host analog signal is slight.

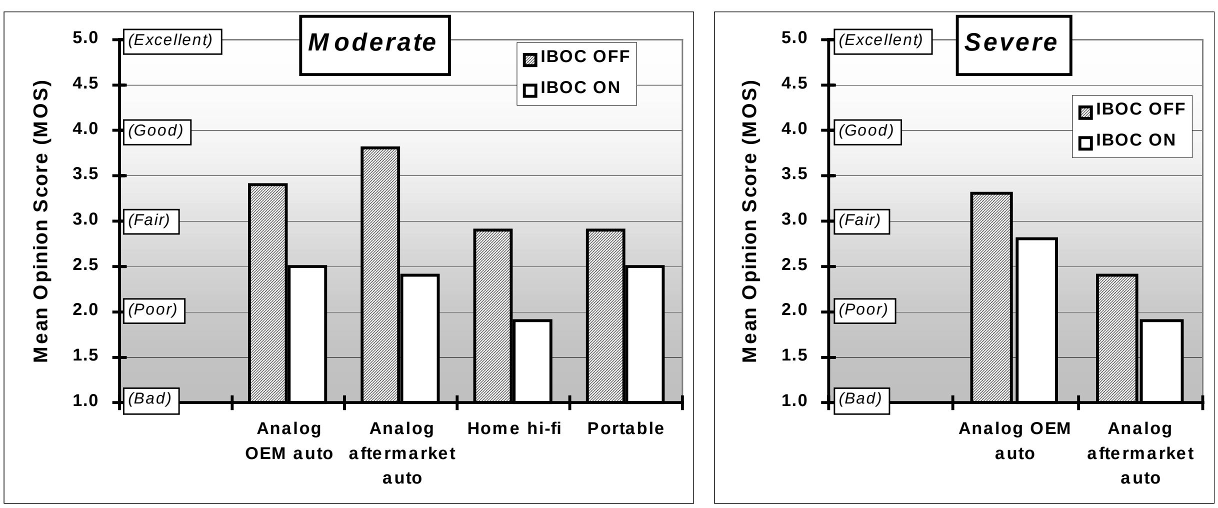

Figure 10. 1st-adjacent compatibility - subjective evaluation results of audio recordings obtained in the field (speech programming)
Moderate: +16 to +6 dB D/U
Severe: +6 to –9 dB D/U

The results shown in Figure 10 serve to illustrate one of the greatest compatibility challenges facing FM IBOC, operation with 1st-adjacent channel interference (discussed in greater detail below in Section 4.12.2), and were obtained in the presence of moderate (between +16 and +6 dB D/U) and severe (between +6 and –9 dB D/U) 1st-adjacent channel interference. These results indicate that under certain circumstances, for certain radios, the presence of the IBOC digital sidebands will have a noticeable effect on analog receiver audio quality. For example, the audio quality of the analog aftermarket auto radio, under moderate interference conditions, is reduced from the "good" range (with no IBOC present) to the "poor" range (with the IBOC digital sidebands present on a 1st-adjacent channel interferer).

By comparing the difference between the "IBOC off" and "IBOC on" performance for the analog OEM auto radio and the analog aftermarket auto radio shown in Figure 10, for the moderate and severe cases, one of the performance behaviors of analog radios which affects compatibility is highlighted—as the interference level increases, the impact of the IBOC digital sidebands on analog receiver performance becomes less noticeable. Specifically, notice how the difference between IBOC on and IBOC off for the analog aftermarket auto radio (in terms of MOS) is about 1.5 in the moderate case, but only about 0.5 for the severe case, a significant reduction.

This last point, that the amount of interference has a bearing on compatibility, has important ramifications for laboratory testing, since one important interference signal which exists in all radio reception environments, that of RF "background noise," is not normally present when co- and adjacent-channel laboratory tests are performed. Because of this, the NRSC decided to add a background noise component to the RF signals under test during compatibility testing, so that the results of subsequent subjective evaluation would be more realistic. The actual amount of RF white noise added, corresponding to 30,000K, was based on studies done by iBiquity.[18] Lab measurements were also made with no added noise as a "sanity check," providing a baseline for comparison in case the results with the artificial noise added turned out to be very different than the real world results obtained in the field. As was expected, the 30,000K results did not turn out to be very different from the field results.

4.3 Evaluation criteria

The EWG utilized 10 criteria for evaluating the data contained in the FM IBOC Test Data Report. Each criterion falls into one of the (previously mentioned) two general categories of results: "digital performance," which applies to performance of the IBOC digital signal, and "analog compatibility," which addresses the impact of the IBOC signal on reception with existing analog receivers. Table 9 lists the evaluation criteria according to category; refer to Appendix E for a detailed description of each criterion, and to Appendix F for a matrix that illustrates which tests (contained in the test procedures) have a bearing upon which criteria.

[18] A summary of these studies was prepared for the NRSC by iBiquity - see "NRSC Noise Report," November 2001.

Table 9. EWG evaluation criteria

DIGITAL PERFORMANCE	ANALOG COMPATIBILITY
Audio quality Service area Durability Acquisition performance Auxiliary data capacity Behavior as signal degrades Stereo separation Flexibility	Host analog signal impact Non-host analog signal impact

As previously mentioned, the goals listed in Table 8 above were used to guide the EWG's assessment of how the IBOC system performed compared to existing analog services. In many cases (as is noted in the "analog benchmark" columns of the test result tables below, *e.g.*, Table 10) analog benchmark data was collected along with the IBOC system data; for compatibility tests, the "IBOC off" data was used as a benchmark (and compared against the "IBOC on" data obtained under otherwise identical conditions, four and one-half second time delay between analog and digital notwithstanding).

4.4 Criterion 1 – Audio quality

Table 10 lists the test results pertaining to audio quality of the iBiquity FM IBOC system.

Table 10. FM IBOC test results pertaining to audio quality

TEST NO. (PROCEDURES)	OBJECTIVE DATA	SUBJECTIVE DATA	ANALOG BENCHMARK	RESULTS / COMMENTS
Field - various	n/a	Appendix K: - Fig. 1, pg. 2 - Figs. 2-9, pgs. 4-11 - Fig. 10, pg. 12	Impairments observed in automotive receivers	"Ticker test" - audio from analog receivers contained 4-5 times more impairment events (6-7 times the number of severe impairment events) than audio from IBOC receivers
Field – various	n/a	Main report: - Fig. 1, pg. 9	Audio quality of automotive receivers	Subjective evaluation of field test data – aggregated results

As defined by the EWG, this criterion relates specifically to the audio quality of the main channel audio signal received under unimpaired conditions i.e. in the absence of RF noise, interfering signals, multipath interference, weak signal conditions, or any other circumstance which would adversely affect reception. Because the results of such tests are in effect a test of the perceptual audio coding algorithm used, and because the iBiquity system hardware tested for the purposes of this evaluation did not utilize the audio coding algorithm to be used in the final deployed version of the system, the NRSC is, strictly speaking, not able to come to any conclusions for this criteria.

However, subjective evaluations of audio obtained in the field (for example, Figure 7 above) strongly suggest that the audio quality of IBOC digital audio will be a significant improvement over the audio quality of existing FM analog if the definition of audio quality is expanded to include that experienced by mobile radio listeners. This of course assumes that the performance of the iBiquity audio coding algorithm meets or exceeds that of the MPEG-2 AAC algorithm used in the hardware tested by the NRSC.

4.4.1 Findings

The iBiquity hybrid FM IBOC system with MPEG-2 AAC perceptual audio coding demonstrates significantly improved audio quality compared to existing analog FM in mobile listening environments. Since the final version of this system will utilize a proprietary iBiquity perceptual audio coding algorithm and not MPEG-2 AAC, no direct findings on the unimpaired audio quality of the final system can be made at this time.

4.5 Criteria 2, 3 – Service area, durability

Table 11 lists the test results pertaining to service area and durability of the iBiquity FM IBOC system. These two criteria have been combined in this section because they essentially share the same list of tests (from the test procedures) from which conclusions can be drawn.

Table 11. FM IBOC test results pertaining to service area and durability

TEST NO. (PROCEDURES)	OBJECTIVE DATA	SUBJECTIVE DATA	ANALOG BENCHMARK	RESULTS / COMMENTS
Lab - B.1 - AWGN	Appendix D: - Fig. 1, pg. 25	Appendix D: - Tables 13, 14, pg. 24 Appendix I, pg. 21	None	Classical music audio quality (fair to good) rated poorer than rock, speech (good to excellent)
Lab – B.2 – Multipath with noise	Appendix D: - Fig. 2, pg. 27 (urban slow) - Fig. 3, pg. 27 (urban fast) - Fig. 4, pg. 28 (terrain obstructed) - Fig. 5, pg. 28 (rural fast)	Appendix D: - Tables 15, 16, pg. 26 Appendix I, pg. 21	Subjective only – MOS scores for automotive receivers	IBOC audio quality good to excellent while analog poor to fair for all cases
Lab – C.1 – Impulse noise	Appendix D: - Fig. 6, pg. 30 (120 Hz) - Fig. 7, pg. 30 (120 Hz, 1st adj.) - Fig. 8, pg. 31 (330 Hz) - Fig. 9, pg. 31 (330 Hz, 1st adj.) - Fig. 10, pg. 32 (510 Hz) - Fig. 11, pg. 32 (510 Hz, 1st adj.) - Fig. 12, pg. 33 (1200 Hz) - Fig. 13, pg. 33 (1200 Hz, 1st adj.) - Fig. 14, pg. 34 (1800 Hz) - Fig. 15, pg. 35 (1800 Hz, 1st adj.) - Fig. 16, pg. 35 (2000 Hz) - Fig. 17, pg. 35 (2000 Hz, 1st adj.) - Fig. 18, pg. 36 (PN) - Fig. 19, pg. 36 (PN, 1st adj.)	Appendix D: - Table 18, pg. 37 Appendix I, pg. 26	Subjective only – MOS scores for automotive receivers (only classical program material used)	No 1st-adj. chan. interferer - IBOC audio quality good to excellent while analog poor to good for all cases With +6 dB upper 1st-adj. (hybrid for digital cases, analog for analog cases): - 120, 330 Hz: IBOC audio quality good to excellent while analog poor to good - 510 Hz, 1200 Hz, 1800 Hz, 2000 Hz, PN: IBOC blending to analog

TEST NO. (PROCEDURES)	OBJECTIVE DATA	SUBJECTIVE DATA	ANALOG BENCHMARK	RESULTS / COMMENTS
Lab – C.2 – Airplane flutter	Appendix D: - Table 19, pg. 38	Appendix D: - Table 20, pg. 38 Appendix I, pg. 27	Subjective only – MOS scores for automotive receivers (only classical program material used)	IBOC BLER equaled zero for all cases tested IBOC audio quality good to excellent while analog bad to poor for all cases
Lab – D.1 – Co-channel IBOC ➜ IBOC	Appendix D: - Fig. 20, pg. 39	Appendix D: - Table 22, pg. 40 Appendix I, pg. 22	Subjective only – MOS scores for all 4 analog receivers (only classical program material used)	Blend D/U point +2 dB IBOC audio quality good to excellent while analog failed or bad
Lab – D.2 – Single and dual 1st adjacent IBOC ➜ IBOC	Appendix D: - Fig. 21, pg. 41 (single 1st) - Fig. 22, pg. 41 (dual 1st)	Appendix D: - Table 24, pg. 40 Appendix I, pg. 22, 23	Subjective only – MOS scores for all 4 analog receivers	Blend D/U point, single 1st: -30 dB; dual 1st: +21 dB IBOC audio quality, single 1st: good to excellent while analog failed or bad IBOC audio quality, dual 1st: good while analog either good (auto) or bad to poor (home, portable)
Lab – D.3 – Single and dual 2nd adjacent, simultaneous single 2nd and single 1st adjacent IBOC ➜ IBOC	Appendix D: - Fig. 23, pg. 42 (single 2nd) - Fig. 24, pg. 43 (single 2nd and single 1st) - Fig. 25, pg. 43 (dual 2nd)	Appendix D: - Table 26, pg. 44 Appendix I, pg. 22, 23	Subjective only – MOS scores for all 4 analog receivers	Blend D/U point: greater than –42 dB (test bed power limit – IBOC never blended) IBOC audio quality, single or dual 2nd: good while analog were failed IBOC audio quality, single 1st and single 2nd: fair to good while analog were failed
Lab – E.1 - Co-channel IBOC ➜ IBOC with multipath	Appendix D: - Fig. 26, pg. 46 (urban slow) - Fig. 27, pg. 46 (urban fast) - Fig. 28, pg. 47 (terr. obstructed) - Fig. 29, pg. 47 (rural fast)	Appendix D: - Table 28, pg. 48 Appendix I, pg. 24	Subjective only – MOS scores for automotive receivers	Blend D/U point: 6-8 dB higher than no multipath case IBOC audio quality good to excellent while analog bad to poor
Lab – E.2 – Single and dual 1st adjacent IBOC ➜ IBOC with multipath (US – urban slow UF – rural fast TO – terrain obstructed RF – rural fast)	Appendix D: - Fig. 30, pg. 49 (US, single 1st) - Fig. 31, pg. 50 (UF, single 1st) - Fig. 32, pg. 50 (TO, single 1st) - Fig. 33, pg. 51 (RF, single 1st) - Fig. 34, pg. 51 (US, dual 1st) - Fig. 35, pg. 52 (UF, dual 1st) - Fig. 36, pg. 52 (TO, dual 1st) - Fig. 37, pg. 53 (RF, dual 1st)	Appendix D: - Table 30, pg. 53-54 Appendix I, pg. 24	Subjective only – MOS scores for automotive receivers	Blend D/U point, single 1st: approx. 21-25 dB higher than no multipath case; dual 1st: approx. 15 dB higher than no multipath case except for terrain obstructed which is 30 dB higher IBOC audio quality, single 1st: good to excellent while analog poor to fair. IBOC audio quality, dual 1st: good to excellent while analog poor to good.

TEST NO. (PROCEDURES)	OBJECTIVE DATA	SUBJECTIVE DATA	ANALOG BENCHMARK	RESULTS / COMMENTS
Lab – E.3 – Single and dual 2nd adjacent, simultaneous single 2nd and single 1st adjacent IBOC ➜ IBOC with multipath (US – urban slow UF – rural fast TO – terrain obstructed RF – rural fast)	Appendix D: - Fig. 38, pg. 56 (US, single 2nd) - Fig. 39, pg. 56 (UF, single 2nd) - Fig. 40, pg. 57 (TO, single 2nd) - Fig. 41, pg. 57 (RF, single 2nd) - Fig. 42, pg. 58 (US, single 2nd and single 1st) - Fig. 43, pg. 58 (UF, single 2nd and single 1st) - Fig. 44, pg. 59 (TO, single 2nd and single 1st) - Fig. 45, pg. 59 (RF, single 2nd and single 1st) - Fig. 46, pg. 60 (US, dual 2nd) - Fig. 47, pg. 60 (UF, dual 2nd) - Fig. 48, pg. 61 (TO, dual 2nd) - Fig. 49, pg. 61 (RF, dual 2nd)	Appendix D: - Table 32, pg. 62-63 Appendix I, pg. 25	Subjective only – MOS scores for automotive receivers	Single 1st and single 2nd terrain obstructed case – performance vs. D/U is flat IBOC audio quality, single 2nd: good to excellent while analog fair to good. IBOC audio quality, single 2nd and single 1st: blending to analog for terrain obstructed case, otherwise good while analog poor to fair. IBOC audio quality, dual 2nd: good to excellent while analog fair to good.
Field – B.1, B.2 – System performance - low interference and low multipath, 1st adj. channel interference	Main report: - Table 5, pg. 13 (list of 1st-adj interferers) - Fig. 8, pg. 18 (KWNR – perf. on Las Vegas Blvd.) - Fig. 9, pg. 19 (WNEW – perf. in downtown NYC) - Fig. 10, pg. 20 (KLLC – perf. in downtown SF) – Fig. 11, pg. 21 (WHFS – perf. in downtown Wash., DC) - Fig. 12, pg. 22 (WWIN digital coverage vs. interferers) Appendix F1 (WETA cov. maps) Appendix F2 (WPOC cov. maps) Appendix F3 (WHFS cov. maps) Appendix F4 (WNEW cov. maps) Appendix F5 (WWIN cov. maps)	Main report: - Fig. 18, pg. 28 - Fig. 21, pg. 31 - Fig. 22, pg. 32 Appendix I, pg. 12 (WETA, WPOC, WNEW only)	Audio quality of host analog signal (recorded simultaneously with IBOC audio)	Digital coverage comparable to analog coverage along test radials. WWIN demonstrated good performance using low-power IBOC/analog combiner WNEW demonstrated good performance using centrally located urban facility, combined antenna Subjective: IBOC audio quality was equal to or better than analog for all audio cuts evaluated
Field – B.3 – System performance – 2nd adj. channel interference	Main report: - Fig. 4, pg. 14 (WNEW digital coverage vs. interferer) - Fig. 5, pg. 15 (KLLC digital coverage vs. interferer) - Fig. 6,7, pgs. 16, 17 (WHFS digital coverage vs. interferer) - Fig. 12, pg. 22 (WWIN digital coverage vs. interferers) Appendix F3 (WHFS cov. maps) Appendix F4 (WNEW cov. maps) Appendix F5 (WWIN cov. maps) Appendix F7 (KLLC cov. maps) Appendix F8 (WD2XAB cov. maps)	Main report: - Fig. 19, pg. 29 - Fig. 20, pg. 30 Appendix I: - Pg. 13 (single 2nd – KLLC, WD2XAB, WNEW only) - Pg. 14 (dual 2nd – WHFS only)	Audio quality of host analog signal (recorded simultaneously with IBOC audio)	Digital coverage comparable to analog coverage along test radials. Subjective: IBOC audio quality was equal to or better than analog for all audio cuts evaluated

TEST NO. (PROCEDURES)	OBJECTIVE DATA	SUBJECTIVE DATA	ANALOG BENCHMARK	RESULTS / COMMENTS
Field – high multipath (not in test procedure)	Main report: Appendix F6 (KWNR cov. maps) Appendix F7 (KLLC cov. maps)	Main report: - Fig. 21, pg. 31 - Fig. 22, pg. 32 Appendix I, pg. 16	Audio quality of host analog signal (recorded simultaneously with IBOC audio)	Subjective: IBOC audio quality rated consistently higher than analog
Field - various	n/a	Appendix K: - Fig. 1, pg. 2 - Figs. 2-9, pgs. 4-11 - Fig. 10, pg. 12	Impairments observed in automotive receivers	"Ticker test" - audio from analog receivers contained 4-5 times more impairment events (6-7 times the number of severe impairment events) than audio from IBOC receivers

As evident from the numerous entries in Table 11, the NRSC's test program contained a substantial number of tests pertaining to these criteria. This seems appropriate since service area and coverage are arguably the most important aspects of a broadcasting service, those which all other aspects build upon. In the sections that follow, test results and details on how service area and coverage are impacted by various types of interference will be given.

In general, these results demonstrate that the "digital" service area of a radio station broadcasting FM IBOC should be an improvement with respect to existing analog service, due primarily to FM IBOC's robustness in the presence of multipath fading. Farther out from the transmitter, as signal strength decreases, the FM IBOC receiver at some point blends to analog (the data suggests this typically occurs at signal levels of 45-50 dBuV/m) and consequently radio service on the edge of coverage will be preserved in its present form for stations broadcasting in hybrid FM IBOC mode. Where exactly blending occurs in these outer areas will depend on nearness to interferers, terrain between the receiver and the transmitter, etc.

4.5.1 With impulse noise

Impulse noise interference can occur in both mobile (*e.g.*, from ignition circuits in automobiles) and household (*e.g.*, from vacuum cleaner motors) environments, reducing the audio quality of radios. The NRSC subjected the iBiquity FM IBOC prototype receiver and the two analog automotive receivers to impulse noise interference at various repetition rates under laboratory conditions. Audio recordings were made under these circumstances and then subjectively evaluated, the results of which are shown in Figure 11.

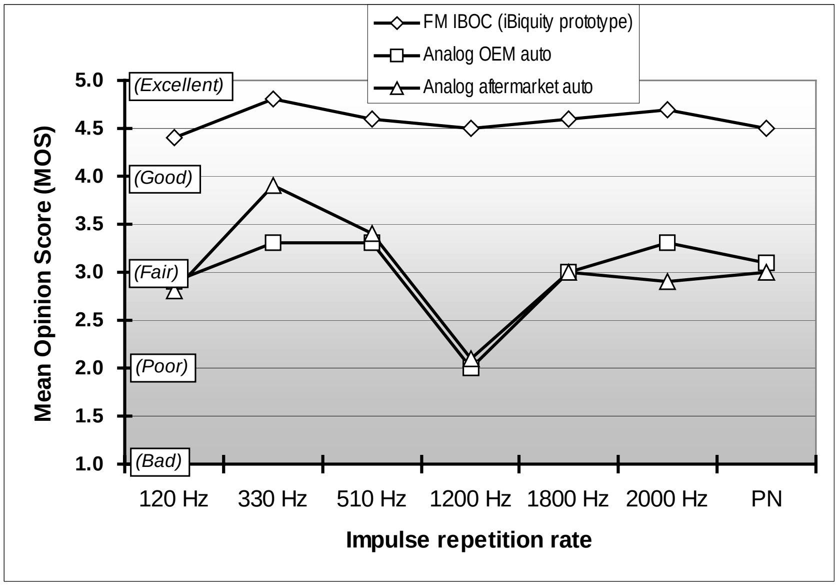

Figure 11. Comparison of FM IBOC and analog audio subjective evaluation results under laboratory impulse noise conditions

These results indicate that the FM IBOC receiver performs significantly better than the analog automotive radios for all impulse repetition rates tested. A second test, identical to the one just described except with the addition of an upper 1st-adjacent channel interferer (at +6 dB D/U) yielded similar results for repetition rates of 120 Hz and 330 Hz, however for the remaining repetition rates the FM IBOC receiver was either blending back and forth between digital and analog audio, or was blended to analog all together.

Overall these results demonstrate that FM IBOC is significantly more robust when subjected to impulse noise interference than is existing analog FM.

4.5.2 With co-channel interference

To determine the performance of the FM IBOC system in the presence of (FM IBOC) co-channel interference in the laboratory, a co-channel interferer was introduced and increased in power level until the desired FM IBOC signal blended to analog. In this manner it was established that a +2 dB D/U ratio was required to cause the desired signal to blend to analog.

After establishing the +2 dB blend point, the level of interference was reduced by 2 dB (resulting in a +4 dB D/U) and recordings of the FM IBOC receiver audio (now digital audio since the operating point had been "backed off" from where the system blends) and audio from the four analog receivers were made. Note that both the desired and undesired signals supplied to the analog receivers were FM analog (not hybrid IBOC), set for a D/U of +4 dB. Under these conditions, two of the analog receivers failed (OEM auto, home hi-fi); recordings from the remaining receivers were subjectively evaluated (Figure 12).

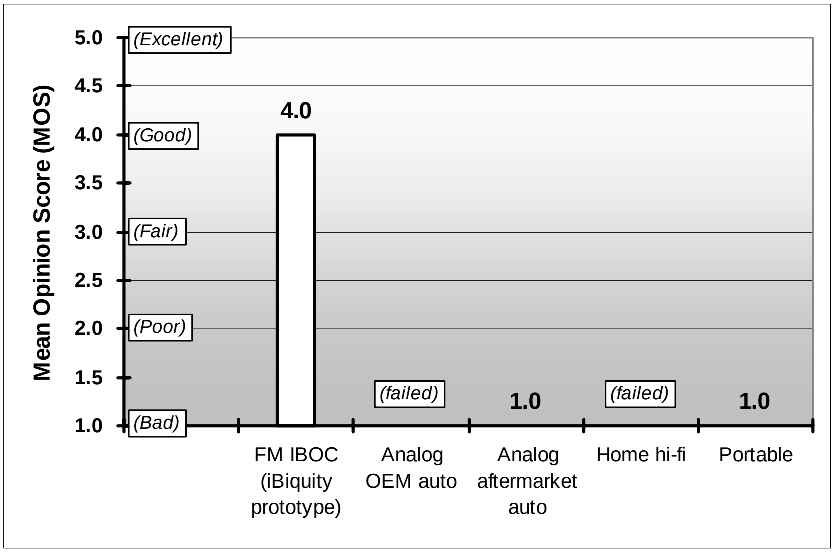

Figure 12. Comparison of FM IBOC and analog audio subjective evaluation results with co-channel interference (+4 dB D/U)

Additional laboratory tests were done using the four multipath scenarios called for in the test procedures (rural fast, terrain obstructed, urban fast, urban slow) and the results were essentially the same, with FM IBOC far outperforming analog FM.

These results demonstrate that FM IBOC is significantly more robust to co-channel interference than is existing analog FM. Amazingly, the FM IBOC receiver achieved "good" audio quality (at the +4 dB D/U operating point) while the analog receivers were either totally failed or exhibiting the lowest quality allowed on the MOS rating scale ("bad"). Note that this operating point is well beyond (by 16 dB) the value to which analog stations are currently protected from co-channel interference.

4.5.3 With 1st-adj. chan. interference

Extensive testing in both the laboratory and the field was conducted to determine the performance of the FM IBOC system in the presence of 1st-adjacent (hybrid FM IBOC) interference. This is an important case to consider because as a consequence of the system design, the digital sidebands of an FM IBOC signal are vulnerable to interference from a 1st-adjacent signal (as shown in Figure 2 above).

Subjective evaluation results from field test data collected on FM IBOC performance with a single 1st-adjacent channel is given in Figure 13. The graphs included in this figure compare the FM IBOC audio quality with that of the host analog signal (obtained simultaneously to insure that the RF signal conditions were the same for both the IBOC and analog audio). An inspection of these graphs indicates that the FM IBOC audio quality either equals or surpasses that of the host analog signal under 1st-adjacent channel interference conditions—note that while there are significant variations in the analog receiver quality, the IBOC receiver quality is consistently in the "good" to "excellent" range.

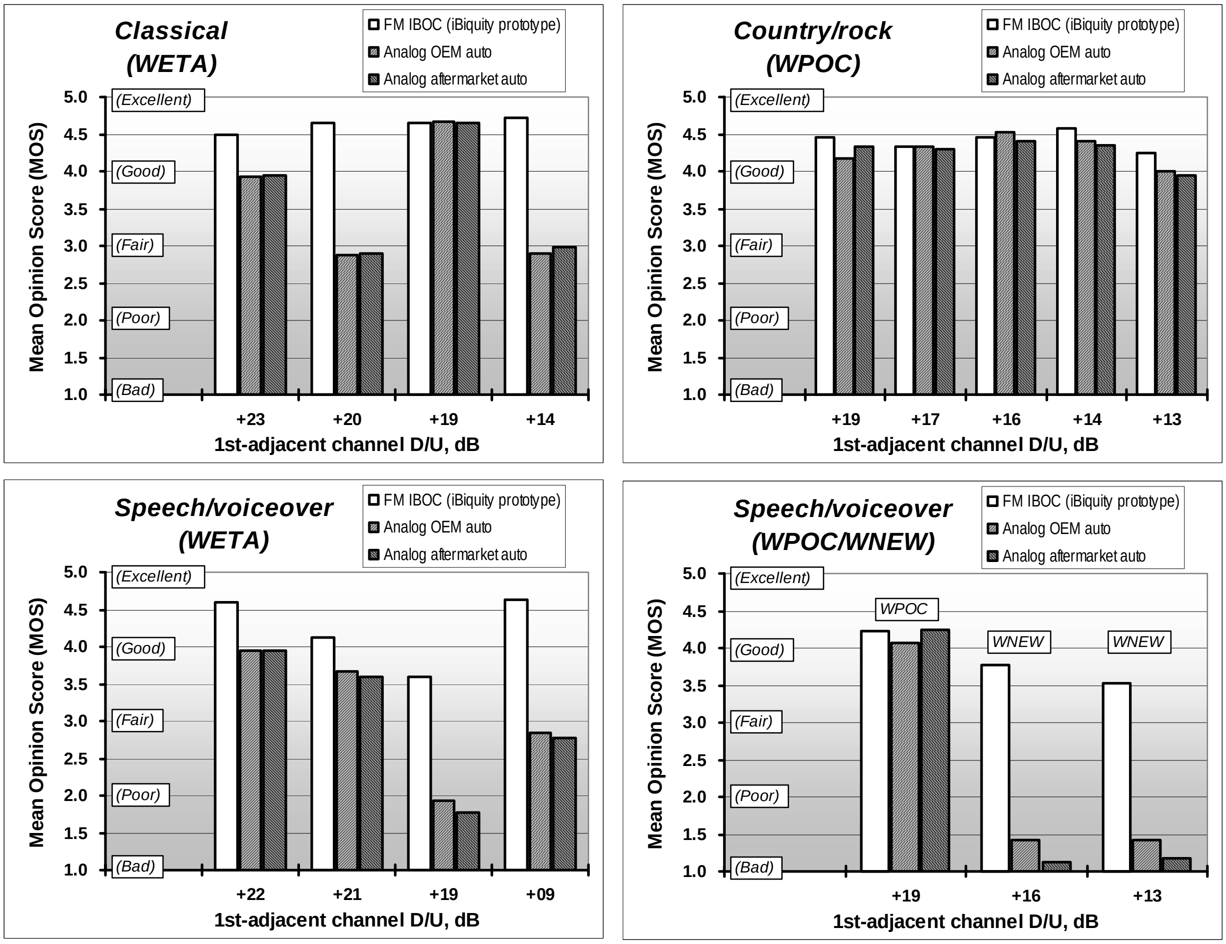

Figure 13. Comparison of FM IBOC and analog audio subjective evaluation results with 1st-adjacent channel interference

Tests were also done (in the laboratory) on digital performance in the presence of dual 1st-adjacent channel hybrid IBOC interferers, utilizing an upper 1st-adj. interferer at +6 dB D/U, and a lower 1st-adj. interferer whose power level was increased until the IBOC receiver started blending to analog. For this test, blending occurred when the lower 1st-adj. chan. interferer was at a D/U ratio of approximately +21 dB. This result is not surprising, since (as was mentioned in Section 3.1 above), at least one of the digital sideband groups is needed for generation of digital audio, and in the case of dual 1st-adjacent channel interference both IBOC sidebands groups are being interfered with, resulting in the need for the system to blend to analog.

4.5.4 With 2nd-adj. chan. interference

Laboratory tests of digital performance in the presence of single and dual 2nd-adjacent IBOC interferers established that the iBiquity FM IBOC system is extremely robust with respect to this type of interference, and confirms that the 4 kHz guard band between 2nd-adjacent IBOC digital sidebands (see Figure 3 and discussion in Section 3.1 above) is adequate. Specifically, even when the D/U ratio was set to the laboratory test bed limit of -42 dB (for single interferer) or to -42 dB (lower), -20 dB (upper) in the dual interferer case, the system did not experience any blending to analog.

In the field, results were obtained in the presence of a 2nd adjacent analog signal at a number of test sites. The 90º radial from field test site WNEW is a good illustration of this (Figure 14). This radial is on a direct line with the transmitter of WBAB, a lower 2nd adjacent channel station. As can be seen in the figure, digital coverage for WNEW extended to the 100 dBu contour of WBAB, at which point the IBOC receiver was experiencing a D/U ratio of approximately –47 dB (7 dB more severe than the FCC protection ratio for 2nd adjacent signals).

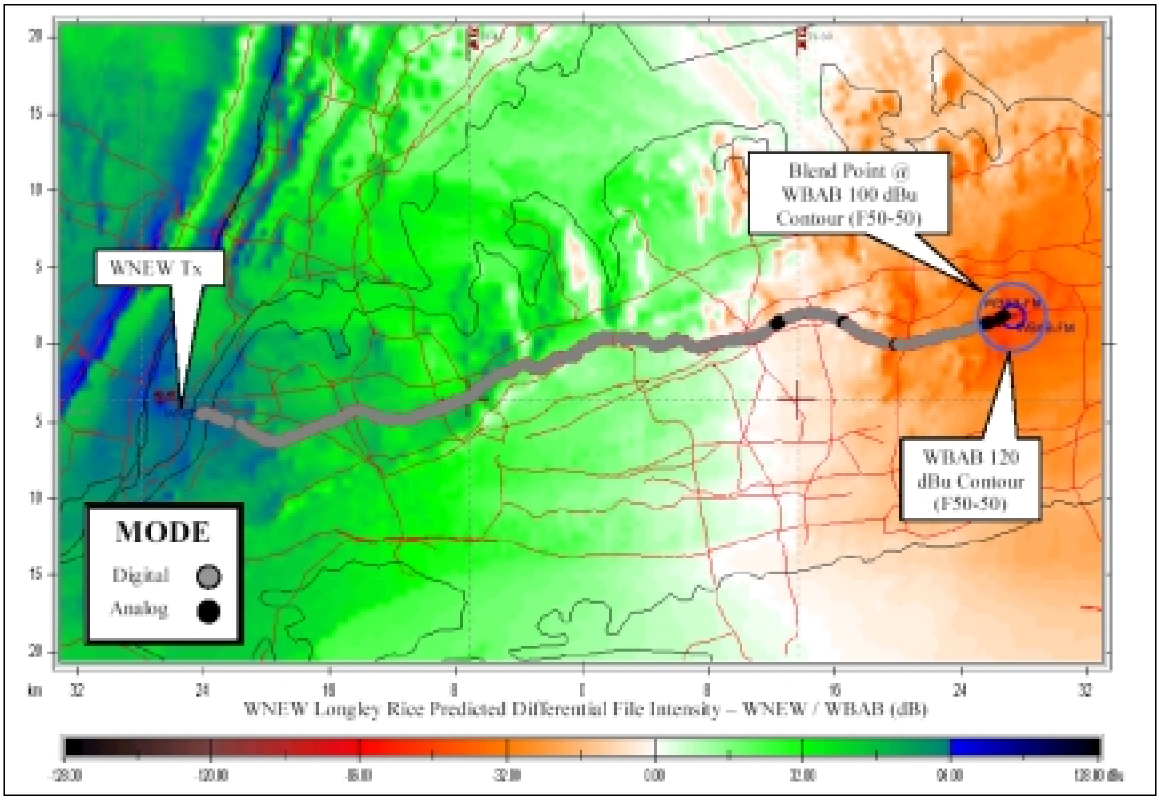

Figure 14. Field test radial illustrating 2nd-adjacent channel performance (WNEW, 90º radial)

4.5.5 With multipath

Of all the benefits provided listeners by IBOC technology, improved performance in the presence of multipath interference is likely to be the most profound. Laboratory and field testing indicates that compared to analog FM, FM IBOC is significantly more robust in the presence of multipath. A good example of this is shown in Figure 15, a digital coverage map obtained in Manhattan of an IBOC signal broadcast from WNEW, which indicates that the IBOC receiver operated without any blends to analog except in one location (related to passage through a tunnel) despite the high levels of multipath typical of Manhattan’s urban canyons. Similar examples of robust urban performance exist from field tests performed in Las Vegas, NV, San Francisco, CA, and Washington, DC.

Figure 15. Map showing FM IBOC digital coverage along route in Manhattan, NYC.

In Figure 16, IBOC receiver performance is compared to analog automotive receiver performance in the laboratory when subjected to multipath interference, for four distinct types of multipath interference. In each case, the FM IBOC audio quality is good to excellent while under identical conditions, the analog audio quality ranges from poor to fair.

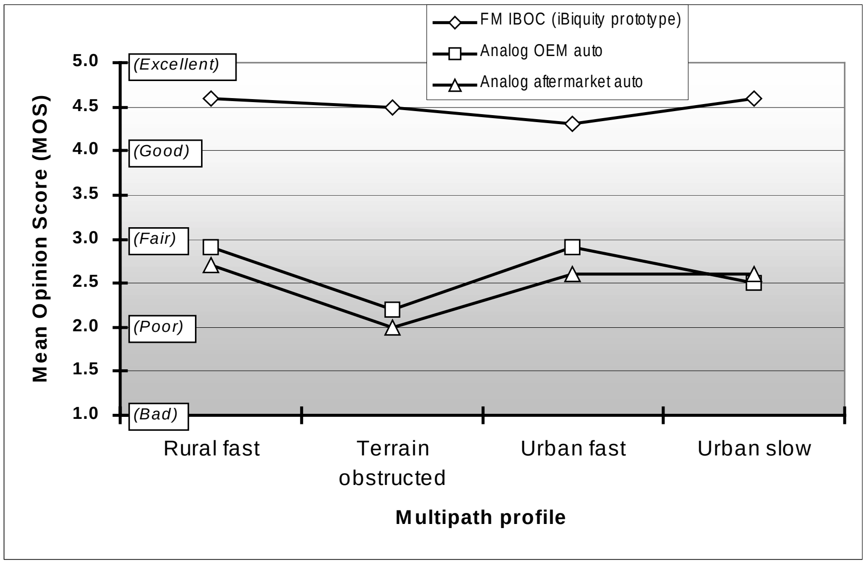

Figure 16. Comparison of FM IBOC and analog audio subjective evaluation results under laboratory multipath conditions

4.5.6 Versus broadcast antenna configuration and combining system

To test the performance and durability of iBiquity's IBOC system under different antenna and combiner configurations, field test stations were specifically selected to include a centrally-located urban antenna, a combined antenna, a low power IBOC combiner/common amplification system and a high power IBOC combiner system.

Most of the field test stations employed a high power combiner system to multiplex the analog and IBOC signals into the test station's existing antenna. The high power system uses separate transmitters for the IBOC and analog signals. The outputs of both transmitters are then combined using a 10-dB coupler. This type of combiner is a relatively simple four-port device consisting of two inputs, an output and dummy load connection. This type of combiner was utilized because of its simplicity and minimal impact on the analog operating power. However, since 90 percent of the IBOC energy input into the combiner is lost to the dummy load, higher IBOC transmitter output power is required to overcome the combining system losses.

WWIN, Glen Burnie, Maryland, employed a low power/common amplification system for multiplexing the IBOC and analog transmissions. In a low power/common amplification system the outputs of the IBOC and analog exciters are combined prior to amplification by a single transmitter. While the combining components employed in low power/common amplification system are considerably smaller, such an implementation requires the use of a transmitter employing a class A or class AB amplifier operation.

WNEW, New York, New York, utilizes a combined antenna in a centrally located urban environment. The Empire State Building master FM antenna, employed by WNEW, is shared with 12 other New York area stations. The WNEW IBOC operation was implemented by using a high power combining system prior to the master FM antenna combiner. No modifications nor tuning of the master FM antenna combiner were necessary to implement IBOC on WNEW.

In each case, no detrimental impact on IBOC performance or durability was observed due to the transmitting antenna or combining system employed. The maps and field strength graphs included as Appendix F of iBiquity's report demonstrate that IBOC performance results for WWIN and WNEW are comparable with other field test stations. The field tests on these different transmission systems serve to demonstrate the flexibility of the IBOC system.

4.5.7 Comparison of measured digital to predicted analog coverage

iBiquity submitted a series of maps depicting the predicted coverage of eight IBOC test stations[19] and the measured performance of each station's IBOC signal. This section of the EWG report contains a brief discussion of those maps as they pertain to comparing analog performance with digital performance within a station's coverage area.

For the iBiquity field test report submitted to the NRSC, audio samples and signal measurements were collected using receiving antennas that were placed relatively close to the ground, as would be the case with typical mobile, portable, and fixed receivers. Nominally, the receiving antenna height was approximately 2 meters (7 ft) above ground level. Signals were measured utilizing a calibrated spectrum analyzer connected to a calibrated sample feed from the antenna.

This signal strength information is depicted in a series of graphs submitted with the maps (Figure 17). Each field intensity graph presents the data collected on one radial drive test and contains field strength of the desired signal and of the upper and lower first adjacent channels, plus the digital-vs.-blend mode of the received digital and the distance from the transmitter. (Note that iBiquity utilized the signal strength information depicted in these graphs to tune the accuracy of the predictive signal strength maps it prepared for submission.)

[19] Stations represent a variety of terrain conditions, station classes and potential interference scenarios. See Table 4 in Section 3.3 above.

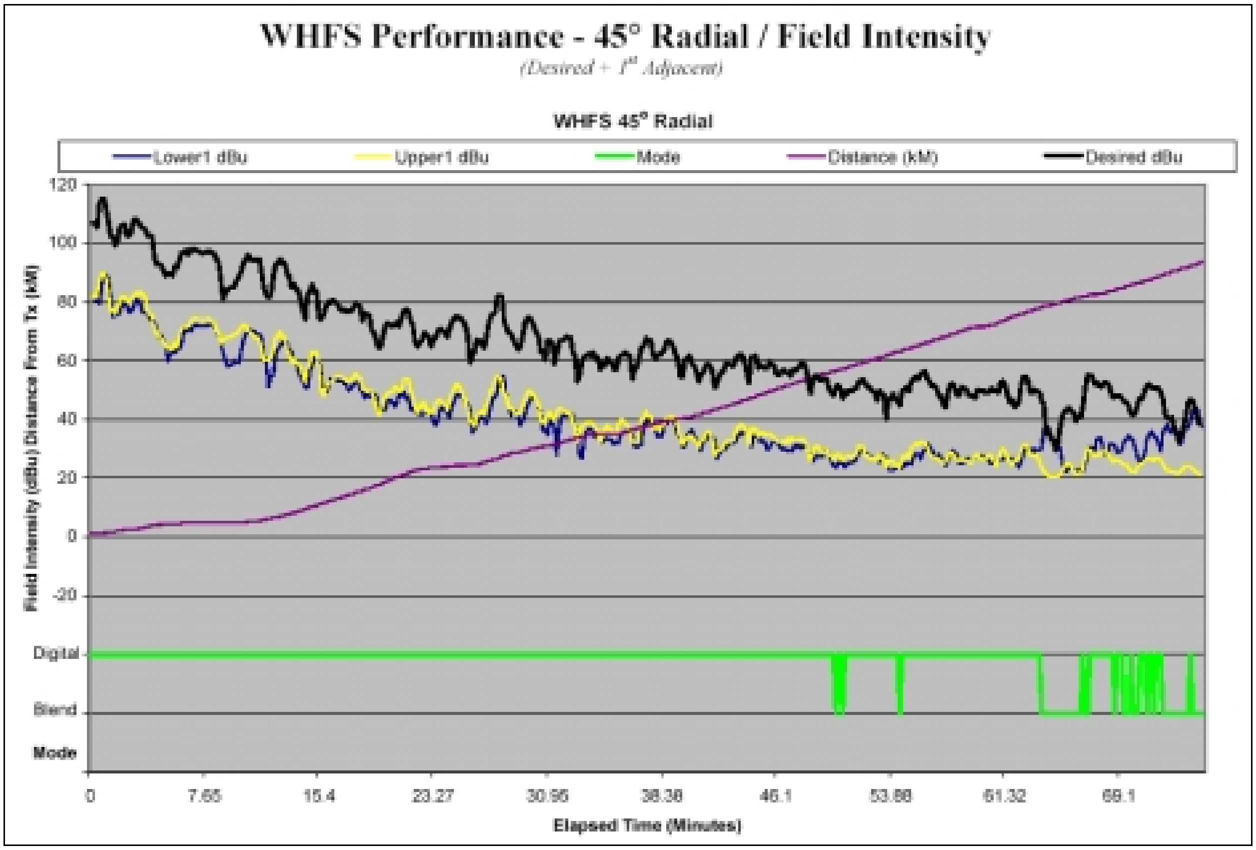

Figure 17. Field test signal strength graph (WHFS, 45º radial)

The test station coverage maps contained in the report each show two images overlaid to enable a comparison between predicted analog signal strength and actual digital IBOC reception (Figure 18; note that this map has been modified by the EWG as will be discussed below). The predicted signal strength information in these maps was generated with ComStudy software and appears as an underlay on each map. The underlay appears on the entire map as a continuum of regions of various colors. The continuum is formed by a matrix of colored pixels. Each pixel represents the predicted signal strength at the pixel's location on the map. The elevation at the location of each pixel is determined from the ComStudy digital elevation model, which has a three-second resolution. The signal strength at each pixel is predicted by employing the elevation data with ComStudy's Longley-Rice calculations. To simulate realistic reception conditions the propagation mode employs a receiving antenna height of 7 ft. (2 meter) above ground. On the transmitting side, the station's site, power, and antenna height above ground are entered in the computation.

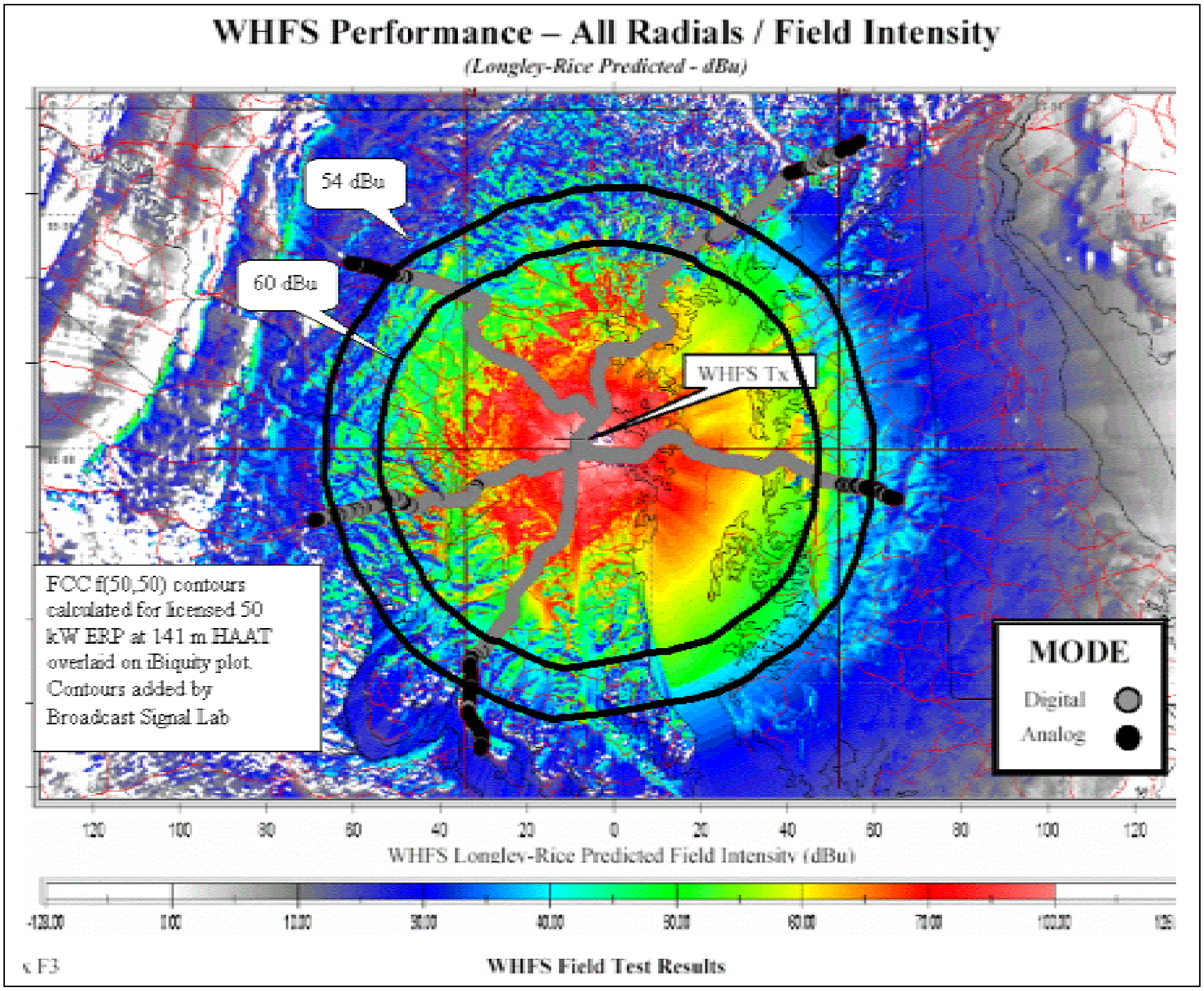

Figure 18. Coverage map including IBOC digital coverage (on radials), predicted field strength, and FCC 54 µV and 60 µV contour

The digital reception data are overlaid upon the propagation data and appear as sets of "worm trails" on the maps. The data were taken from mobile tests in which the test vehicle was driven on roads that generally radiate from the transmitter sites of the test stations. The data from which the worm trails were generated is presented on the signal strength graphs that accompany the maps. The worm trails indicate one of two conditions; either the digital signal was being received reliably (shown in gray), or the receiver had blended to analog (shown in black). No information was given to indicate what the quality of the blended-to-analog signal was. Hence, the digital reception radial drive test maps indicate positively where digital reception was reliable, but give no direct comparative information on the quality of the analog coverage of the station.

The iBiquity predicted signal strength underlays give a reasonably accurate picture of how the terrain affects reception of each radio station. They permit the map-reader to compare the predicted analog signal strength with digital performance.

The Evaluation Working Group found the iBiquity maps to be very helpful as a means of geographically comparing digital and analog performance of these IBOC stations. Because the signal strength predictions are based on actual terrain conditions and on typical receiving antenna heights, they do not depict official protected contours. The Evaluation Working Group chose to enhance these already insightful maps by adding predicted contours of 60 dBμ and 54 dBμ. An example of the results of these enhancements is shown on the map above (Figure 18).

These images permit the reader to compare the three relevant conditions for each station tested. Predicted strength of the analog signal is readily compared with both the FCC contours and the digital performance worm trails. The relationship between the digital performance and the FCC contours is also evident.

It is important to note the distinctions between the manner in which the FCC contours and the color signal strength matrix are computed. The color signal strength underlay is computer calculated based on receiving antenna heights of 2 meters and on actual terrain conditions (iBiquity employed field measurement data to adjust the accuracy of the color underlays to account for typical local land cover losses). In contrast, the official FCC F(50,50) contours represent the predicted signal strength at a receiving antenna 30 feet above ground and are based on simplified average terrain calculations.

While the iBiquity color underlays are more accurate representations of station signal strengths than the FCC contours, the inclusion of FCC contours brings the digital IBOC coverage data into the context of FCC interference protection criteria with which broadcasters are so familiar.

The stations presented in the maps illustrate the manner and the varying degrees to which terrain affects actual coverage. The common factor most apparent on the maps is how the digital IBOC signal remains uninterrupted on long traverses from the stations' transmitter sites to more distant locations. The locations where the digital IBOC signal blends to analog are generally indicated as locations where terrain and distance also impede the analog signal strength.

Typically, within a station's primary service area as defined approximately by its protected contour, the digital IBOC signal is extremely reliable wherever there is enough signal strength to support analog reception. When terrain obstructs analog signals significantly within the protected contour, there is no reason to expect the digital coverage to overcome the impact of the terrain obstruction.

At the points where the digital reception blends to the analog signal, the maps do not contain the kind of qualitative information necessary to determine analog performance. Analysis of the analog performance in the regions of blending is discussed in Section 4.8 below.

Similarly, the maps do not indicate locations where multipath conditions affect analog performance in areas of strong signal strengths. Comparison of analog and digital reception under these conditions is discussed in Section 4.5.5 above and in the "Ticker Test" Section 4.5.8 below.

Outside their protected contours it is commonly understood that stations may have some additional coverage that is limited by factors such as interference, terrain, and distance. The digital IBOC signals appear to provide coverage generally in areas where the analog signal strength is at useable levels. The stations may be subjected to interference from adjacent channels in some locations. The issue of co- and adjacent-channel interference to digital IBOC reception is addressed in Sections 4.5.2 through 4.5.4 of this report.

The eight maps submitted by iBiquity represent a variety of station classes, terrain conditions and interference scenarios (see Table 4 above). While these test stations provide a good cross section of various conditions, they of course represent a very small percentage of the FM stations in the U.S. and cannot be employed as the only means of verifying IBOC digital service area. The general association among the maps, between predicted analog signal strength and measured digital performance, does suggest that careful generalizations can be made about digital coverage area to the degree they are supported by lab test data. This data is discussed elsewhere in this Section.

In summary, the IBOC digital coverage maps supplied by iBiquity were verified by the EWG and enhanced with the inclusion of FCC contours. The iBiquity digital coverage maps illustrate how mobile digital reception along routes radiating from eight test stations is extremely reliable within the approximate service areas defined by the protected contours. Within these contours the digital signals do not provide coverage where terrain already prevents analog coverage. Outside the areas defined by the contours, digital reception remains functional where the host analog signals are predicted to be at useable levels. In marginal areas mobile reception may be impeded but careful placement of a fixed receiver may result in reliable digital service. The maps do not account for the possibility that digital service in some cases may be interference limited, so conclusions about interference-limited coverage is left to analysis of other tests.

4.5.8 “Ticker Test”

To amplify upon data taken in the radial drive tests, iBiquity created a “Ticker Test” in which subjects listened to long samples of recorded test audio and “ticked” audible impairments. iBiquity solicited subjects from the general public who met minimum criteria for listening acuity. The Ticker Test illustrates the differences between what could be considered “normal” mobile analog reception within the coverage area and simultaneous digital reception of the same program. Normal mobile reception typically contains multipath and other propagation and interference effects that can degrade the quality of the received analog signal.

The Ticker Test was conducted with a total of eight sets of audio samples taken from the radial drive tests of test stations WETA and WPOC. Each sample was taken beginning at about ten miles distance from the transmitter and lasted for about 5 minutes. Samples were recorded simultaneously from the IBOC receiver and two analog automotive receivers, an OEM model and an aftermarket model. Information about the test is detailed in Appendix K of the FM IBOC Test Data Report.

The subjects made a “tick” each time they heard a transient impairment to the audio to which they were listening. Ticks represent audible impairments, regardless of the cause. Broadcast production errors would likely be common to all receivers tested, while multipath-induced artifacts or audio processing artifacts may be associated specifically with analog or digital reception or with a particular radio.

The total number of ticks earned by each receiver was tabulated for each of eight test recordings. The Delphi and Pioneer automotive radios earned an average of 844 and 1010 ticks respectively per test recording. The FM IBOC average was 180 ticks per test recording (see Figure 8 above).

iBiquity also subjectively tested audio samples from the audio of each Ticker Test. Subjects indicated a consistent preference for the IBOC audio under these typical mobile reception conditions. During the original Ticker Test listeners were able to “tick” a temporal impairment as either moderate or severe. The subjective tests involved audio samples that contained either moderate or severe ticks. With moderate impairments the automobile radios scored in the low “fair to good” range, between 3.0 and 3.5 MOS, under three kinds of programming—classical, country, or speech. The same samples of the IBOC audio scored in the low “good to excellent” range, between 4 and 4.5 MOS. The automobile radio audio samples of severe tick ratings yielded middle “poor to fair” results, around 2.5 MOS. During the periods of severe impairments to analog auto radio reception, the FM IBOC scored consistently “good” at about 4.2 MOS.

The subjective tests of the Ticker Test audio confirm that not only are the audible temporal impairments in mobile reception fewer in number with IBOC than analog, but also that the IBOC audio retains perceived high quality when analog reception is severely degraded.

The EWG found the Ticker Test results to be an impressive demonstration of IBOC's durability under multipath and related signal impairments. The mobile receivers presented about five times the number of audible impairments heard on the IBOC receiver. Listeners preferred the sound of the IBOC radio under the test conditions. Taken by itself, the Ticker Test is not scientifically conclusive. However, the Ticker Test results provide a clear confirmation of other observations in this report that mobile reception of the IBOC digital signal is significantly more immune to audible transient impairments within a station's primary coverage area than is the host analog signal.

4.5.9 Findings – service area

NRSC test results indicate that hybrid FM IBOC digital coverage is comparable to analog coverage along radial and loop routes tested. Due to FM IBOC's improved resistance to various types of interference (co- and adjacent channel, impulse noise, and multipath fading in particular), FM IBOC service may be available in areas where analog service is currently of unacceptable quality due to such interference.

4.5.10 Findings – durability

NRSC test results demonstrate that the iBiquity hybrid FM IBOC system, compared to analog FM, is substantially more robust under impulse noise, co- and adjacent channel interference, and multipath fading conditions.

4.6 Criterion 4 – Acquisition performance

Table 12 lists the test result pertaining to acquisition performance of the iBiquity FM IBOC system.

Table 12. FM IBOC test results pertaining to acquisition performance

TEST NO. (PROCEDURES)	OBJECTIVE DATA	SUBJECTIVE DATA	ANALOG BENCHMARK	RESULTS / COMMENTS
Lab – H.1 – IBOC acquisition	Appendix D: - Table 33, pg. 64	n/a	Acquisition time of analog receiver	IBOC receiver acquisition time – 135 msec; mode - analog

The iBiquity FM IBOC system is designed such that an IBOC receiver will initially acquire an FM channel utilizing the analog portion of the hybrid FM IBOC signal. Once the digital portion of the signal is fully acquired (takes a few seconds), the receiver will then blend from analog audio to digital audio. Consequently, an IBOC receiver has the same acquisition performance as does an analog radio. This was confirmed by NRSC lab test H.1, where the acquisition time was measured to be 135 msec.

4.6.1 Findings

The acquisition performance of the iBiquity hybrid FM IBOC system is identical to that of an analog FM radio since, by design, an IBOC receiver initially acquires the analog portion of the hybrid FM IBOC signal.

4.7 Criterion 5 – Auxiliary data capacity

According to the system specification, the iBiquity FM IBOC system operating in hybrid mode supports transmission of an auxiliary data stream along with the main channel audio data stream with a capacity as shown in Table 13.[20] This system feature was not tested by the NRSC.

Note that the actual capacity supported is inversely related to the main channel audio bit rate such that the sum of the main channel digital audio bit rate and the auxiliary data rate equals 99-100 kbps, with the variability indicated here being due to the fact that part of this capacity is "opportunistic" in nature, depending upon the operation of the perceptual audio codec. The minimum dedicated portion (i.e. non-opportunistic) of the auxiliary data capacity is 1 kbps, and can be increased in 8 kbps increments with a corresponding decrease in the main channel digital audio data rate.

Table 13. Auxiliary data capacity of the iBiquity FM IBOC system - data rates include 2-3 kbps average rate for opportunistic data[21]

Operating mode	With 96 kbps main channel audio	With 64 kbps main channel audio
Hybrid	3-4 kbps	35-36 kbps

4.7.1 Findings

The iBiquity hybrid FM IBOC system design incorporates an auxiliary data transmission feature with a minimum capacity of 3-4 kbps. This system feature was not tested by the NRSC.

4.8 Criterion 6 – Behavior as signal degrades

This criterion pertains to how an IBOC receiver generally behaves as the received signal becomes weak (due to blockage or distance from the transmitter), or encounters severe degradation due to interference (*e.g.*, multipath fading) compared to how an analog receiver would behave under similar conditions. Table 14 lists the test results pertaining to behavior as signal degrades of the iBiquity FM IBOC system.

[20] See FM IBOC Test Data Report, Appendix A.
[21] See FM IBOC Test Data Report, main report, pg. 35, Section E, and Appendix A.

Table 14. FM IBOC test results pertaining to behavior as signal degrades

TEST NO. (PROCEDURES)	OBJECTIVE DATA	SUBJECTIVE DATA	ANALOG BENCHMARK	RESULTS / COMMENTS
Field – Performance at blend (NRSC procedures as amended by Steering Committee)	n/a	Main report: - Fig. 25, pg. 38 Appendix I, pg. 15	Audio quality of host analog signal (recorded simultaneously with IBOC audio)	IBOC audio cuts containing blends (to analog) were tested Subjective results: Audio quality of IBOC with blends nearly identical to corresponding analog

Fundamentally, by virtue of the FM IBOC system's blend to analog feature, an FM IBOC receiver behaves similar to an analog receiver as the signal weakens or otherwise approaches the outer limits of a reception area. This behavior differs from that of other digital broadcast systems which, under similar conditions, exhibit the so-called "cliff effect," whereby the signal transitions from a high-quality digital signal to muting. iBiquity has indicated to the NRSC that the "blend point" of the system has been placed such that blending to analog will occur prior to the point where the received digital audio would start experiencing undesirable, audible artifacts ("clicks," "pops," etc.) due to signal degradation. According to iBiquity, this point is established by monitoring the block error rate (BLER, which increases with increasing signal degradation) as well as the overall error statistics, and blending is initiated at a BLER of approximately 10% (meaning that 10% of the received data blocks have one or more un-correctable errors).

As part of the NRSC evaluation, audio recordings were obtained in the field at the point where the FM IBOC receiver was blending between analog and digital such that the blend process was captured; consequently, this audio is a combination of digital, analog, and the blending between the two. These recordings were then compared subjectively to recordings made on analog automotive receivers at the same time under the same conditions and the results of these evaluations are shown in Figure 19. These results demonstrate both that the FM IBOC audio during the blend process is perceived to have the same quality as does the analog audio, and, that the blend process itself does not degrade the audio quality below that of analog.

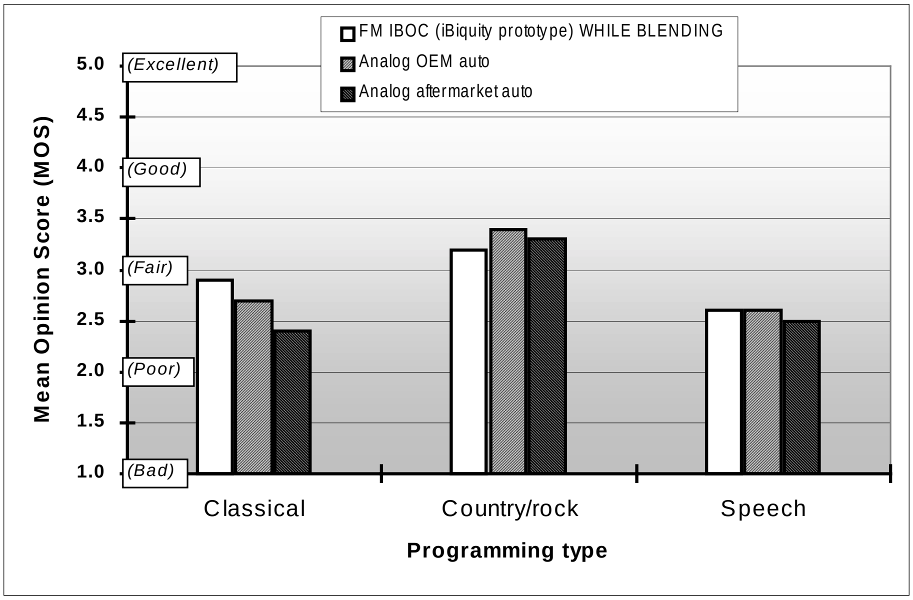

Figure 19. Comparison of FM IBOC and analog audio subjective evaluation results at "blend to analog" operating point

4.8.1 Findings

NRSC testing has demonstrated that the iBiquity prototype hybrid FM IBOC receiver's audio during the blend process is perceived to have the same quality as does the analog audio, and, that the blend process itself does not degrade the IBOC receiver's audio quality below that of analog.

4.9 Criterion 7 – Stereo separation

Unlike the blend to monophonic mode used by the FM automobile radio manufacturers (discussed in Appendix G to this report), the hybrid FM IBOC receiver tested by the NRSC remains in full stereo as long as digital audio is available. Under certain signal conditions (as discussed in Section 3.1 above) the IBOC receiver output blends to analog. Since (as discussed in Appendix G) analog automotive FM receivers blend to mono under a variety of circumstance for which an IBOC receiver (under the same conditions) should still be receiving digital stereo audio, the FM IBOC receiver should exhibit superior stereo separation compared to analog automotive FM receivers.

4.9.1 Findings

FM IBOC receivers are expected to exhibit superior stereo separation compared to analog automotive FM receivers due to the fact that the FM IBOC receiver should be receiving digital stereo audio under circumstances for which an analog automotive FM receiver would be blending to mono.

4.10 Criterion 8 – Flexibility

Appendix A of the FM IBOC Test Data Report, the "IBOC FM Transmission Specification," documents a number of features of the FM IBOC system which should provide significant flexibility for both broadcasters and receiver manufacturers, including:

- Modes of operation: three modes of operation are described—hybrid mode, extended hybrid mode, and all-digital mode—offering significant opportunities for individualizing the broadcast signal to specific needs and for future improvements in system performance. Only the hybrid mode has been tested by the NRSC.

- Audio coding rate: the bit rate used for transmission of the main channel audio signal can be varied, allowing for re-allocation of the digital payload based on a broadcaster's particular requirements. NRSC testing of the FM IBOC system was done with the audio coding rate fixed at 96 kbps (the maximum rate supported in the hybrid mode of operation).

- Auxiliary data rate: (this is discussed in Section 4.7 above in greater detail) the FM IBOC system supports transmission of an auxiliary data stream along with the main channel audio bit stream. The actual amount of auxiliary data transmitted can be decreased or increased in conjunction with a corresponding increase or decrease in the audio coding rate. This system feature was not tested by the NRSC.

- On-channel repeaters: the use of OFDM modulation in the FM IBOC system allows on-channel digital repeaters to fill areas of desired coverage where signal losses due to terrain and/or shadowing are severe. This system feature was not tested by the NRSC.

4.10.1 Findings

There are a significant number of features in the iBiquity FM IBOC system which should provide for system flexibility and should offer broadcasters and receiver manufacturers opportunities to customize services and equipment for their particular goals, and offer the possibility of performance improvements in the future. None of these features were tested by the NRSC.

4.11 Criterion 9 – Host analog signal impact

Table 15 lists the test results submitted pertaining to host analog signal impact of the iBiquity FM IBOC system.

Table 15. FM IBOC test results pertaining to host analog signal impact

TEST NO. (PROCEDURES)	OBJECTIVE DATA	SUBJECTIVE DATA	RESULTS / COMMENTS
Lab – J.1, J.2 - IBOC ➜ host analog (main channel audio)	Appendix D: - Table 5, pg. 15 (Delphi) - Table 6, pg. 15 (Pioneer) - Table 7, pg. 15 (Technics) - Table 8, pg. 16 (Sony)	Appendix D: - Table 11, pg. 22 Appendix I, pg. 28	Objective: Delphi, Pioneer: results with IBOC and analog interferers nearly identical; Technics: IBOC interferer degraded S/N ratio 6-9 dB Sony: IBOC interferer degraded S/N ratio approx. 15 dB Subjective: results with and without IBOC nearly identical
Lab – J.3 - IBOC ➜ host analog (FM subcarriers-spectral plots)	Appendix SCA-A: - Table 9, pg. 22 - Figs. 1-16, pgs. 23-38 (spectral plots with and without IBOC)	n/a	Noise floor in subcarrier region of FM baseband increases with: - addition of IBOC sidebands - addition of main channel audio modulation - addition of RF noise - reduction in RF input signal level
Lab – J.4 - IBOC ➜ host analog (analog FM subcarrier audio quality)	Appendix SCA-A: - Table 10, pg. 39 (67 kHz, McMartin-before repair) - Table 11, pg. 40 (67 kHz, McMartin- after repair) - Table 12, pg. 40 (67 kHz, Norver) - Table 13, pg. 40 (92 kHz, CozmoCom) - Table 14, pg. 41 (92 kHz ComPol)	Appendix SCA-A: - Table 18, pg. 53 Appendix SCA-C, pg. 1	Objective: 67 kHz: McMartin receiver audio S/N reduced 3-8 dB when IBOC present; Norver, 6-12 dB 92 kHz: CozmoCom receiver audio S/N reduced 6-7 dB when IBOC present; ComPol fails (audio S/N reduced to 8-9 dB when IBOC present). Subjective: 67 kHz: McMartin audio quality nearly identical when IBOC present; Norver audio quality reduced from good to fair. 92 kHz: CozmoCom audio quality reduced from poor to bad when IBOC present; ComPol from fair to bad.
Lab – J.5, J.6 - IBOC ➜ host analog (RDS, DARC subcarrier performance)	Appendix SCA-A: - Table 15, pg. 42 (RDS) - Table 16, pg. 43 (DARC)	n/a	Results with and without IBOC identical for both RDS and DARC (in all cases, BLER after correction equals 0)
Field – C.1 – host compatibility (main channel audio)	Appendix F9: - Pg. 1 (WETA locations) - Pg. 2 (WPOC locations)	Main report: - Fig. 26, pg. 40 Appendix I, pg. 17	Results with and without IBOC nearly identical for all 4 analog receivers tested
Field – C.2 – host compatibility (FM subcarriers)	Appendix SCA-B: - Pg. 1 (WPOC locations – 67, 92 kHz analog subcarriers) - Pg. 2 (WPOC locations – RDS digital subcarrier) - Pg. 3 (WD2XAB locations – 67, 92 kHz analog, DARC digital subcarriers) - Pg. 4 (Table – field test strength by test and location) Appendix SCA-D: - Pg. 1 (Table – RDS BLER) - Pg. 2 (Table – DARC BLER)	Appendix SCA-C, pg. 6	Digital subcarriers: Results with IBOC and analog interferers identical for RDS, nearly identical for DARC.

The FM band IBOC digital radio system transmits the digital signals in the first half of the upper and lower host first adjacent channels (see Figure 1 above). The signals are transmitted in two frequency bands that extend from 129 kHz to 198 kHz above and below the host FM channel center frequency. The average total power of the two IBOC digital signals is 20dB below the host FM signal (-20dBc).

Consumer radios have used several methods for decoding the FM stereo difference signal. In practice the PLL stereo decoder has become the norm. The PLL stereo decoder uses square wave switching to decode the 38 kHz stereo difference signal. This decoder is sensitive to signals that are at odd multiples of 38 kHz. Without the addition of filters or special circuitry to the PLL stereo decoder, the IBOC digital signal that is transmitted at 190 kHz (five times 38 kHz) above and below the FM channel center frequency will increase the stereo audio noise floor. Most automobile radios use PLL stereo decoders that are not sensitive to the host IBOC signal. Monophonic radios are not affected by the host IBOC digital signal.

4.11.1 Host compatibility tests

Objective laboratory tests were conducted by the ATTC at strong signal levels with and without 30,000K AWGN. WQP S/N measurements were made with and without the IBOC signal added to the analog. Laboratory objective stereo separation tests were also conducted with less than 1dB separation change with and without the IBOC signal.

The addition of the digital signal caused no measurable change in the host analog S/N performance for the automobile radios, Table 16. The home hi fi radio S/N is reduced to 49dB WQP with the IBOC. The portable radio S/N was reduced to 35dB WQP with IBOC (WQP S/N is typically 10dB lower than RMS).

Table 16. Host compatibility objective laboratory test results at –47 dBm (strong) signal level

RADIO	TYPE	FM ONLY WQP S/N (DB)	IBOC WQP S/N (DB)	FM+AWGN WQP S/N (DB)	IBOC+AWGN WQP S/N (DB)
Delphi	Auto	59	59	56	56
Pioneer	Auto	56	56	54	54
Technics	Home hi fi	59	49	55	49
Sony	Portable/Bookshelf	51	35	49	35

4.11.2 Range of FM stereo hi fi and portable radio sensitivity to the host IBOC signal

Previous receiver laboratory tests conducted by CEA measured the sensitivity to host digital signals on 15 FM stereo radios. Five of the radios tested were automobile, one top-of-the-line tuner, and the remaining nine were home hi fi and portable. These tests were conducted using a simulated IBOC signal, with the digital signal operating at –22 dBc, 2dB lower than the present level. The 2dB lower IBOC level should not make a difference in establishing a range of FM stereo radio S/N performance with IBOC.

Table 17 lists the nine hi fi and portable radios tested by CEA and shows the difference in S/N performance caused by the addition of the IBOC signal, in descending order. Radios 1 and 8 are of the same make and almost identical radios to those used for the IBOC laboratory and field tests. The changes in the newer models were more cosmetic than electronic.

Table 17 shows that the Technics hi-fi (no. 1) and the Sony table/portable (no. 8) radios, the type used for the IBOC laboratory and field tests, are at the high and low ends for the range of the S/N performance.

Table 17. Simulated IBOC to host FM stereo performance range table (hi-fi and portable receivers)

NO.	MAKE	TYPE	PREDICTED S/N RANGE (RMS, dB)
1	**Technics**	**hi fi**	**Reference**
2	Denon	hi fi	0
3	Sony	Personal Portable	–3
4	Sony	hi fi	–4
5	Magnavox	Table/Portable	–4
6	Panasonic	Portable	–7
7	Pioneer	hi fi	-10
8	**Sony**	**Table/Portable combo**	**–11**
9	Sanyo	Shelf combo	-12

4.11.3 Laboratory subjective tests

Audio recordings were made with three types of processed program material: classical, rock, and speech. The subjective tests were conducted at a separate specialized audio subjective evaluation laboratory. Using the MOS rating on a scale of five, the Delphi radio deviated no more than 0.1 MOS units with any combination of FM, IBOC, or AWGN. The Pioneer with AWGN showed a decrease in performance of 0.4 from the analog for both classical and speech. There was no change in S/N or stereo separation for this test. The Sony radio S/N changed from 51dB to 35dB with IBOC, and the subjective performance changed from 2.9 without IBOC to 3.1 with IBOC.

4.11.4 Field subjective tests

Only subjective host compatibility tests were conducted. The tests were conducted at fixed sites. Three types of off-air program material were selected: classical, country/rock, and speech. For the classical and country/rock the largest deviation with IBOC for all four radios was 0.2 MOS. For the speech transmissions the largest deviation with IBOC was 0.3 MOS for all four radios. See Figure 9 above for graphs showing host compatibility subjective evaluation results.

4.11.5 Findings

NRSC tests indicate that listeners should not perceive an impact on analog host reception due to hybrid FM IBOC operation.

4.12 Criterion 10 - Non-host analog signal impact

In this section, the compatibility of an IBOC signal with co- and adjacent-channel analog signals will be considered. Table 18 describes where the test results pertaining to the non-host analog signal impact of the iBiquity FM IBOC system may be found in the FM IBOC Test Data Report, and provides some brief comments about these results. A more detailed analysis is provided in the paragraphs that follow.

Table 18. FM IBOC test results pertaining to non-host analog signal impact

TEST NO. (PROCEDURES)	OBJECTIVE DATA	SUBJECTIVE DATA	RESULTS / COMMENTS
Lab – F.1, F.3 - IBOC ➜ analog (main channel audio), single 1st adj.	Appendix D: - Table 1, pg. 7(Delphi) - Table 2, pg. 9 (Pioneer) - Table 3, pg. 11 (Technics) - Table 4, pg. 13 (Sony)	Appendix D: - Table 9, pg. 18 Appendix I, pg. 29-31	Objective: Delphi: IBOC interferer degraded performance at +6, -4, -14 dB D/U, performance with analog severely degraded at -24 dB D/U so IBOC impact not meaningful; Pioneer: IBOC interferer degraded performance at +6 and -4 dB D/U, performance with analog severely degraded at -14 and -24 dB D/U so IBOC impact not meaningful; Technics: performance with analog severely degraded at +6, -4, -14 and –24 dB D/U so IBOC impact not meaningful; Sony: performance with analog severely degraded at +16, +6, -4, -14 and –24 dB D/U so IBOC impact not meaningful; Subjective: Delphi, Pioneer, Technics: IBOC interferer degraded performance at +6 and –4 dB D/U, impact most significant for speech programming; Sony: results with IBOC and analog interferers nearly identical
Lab – F.2, F.4 - IBOC ➜ analog (main channel audio), single 2nd adj.	Appendix D: - Table 1, pg. 7(Delphi) - Table 2, pg. 9 (Pioneer) - Table 3, pg. 11 (Technics) - Table 4, pg. 13 (Sony)	Main report: - Fig. 36, pg. 54 - Fig. 37, pg. 55 Appendix D: - Table 9, pg. 18 Appendix I, pg. 32-33	Objective: Delphi, Pioneer: results with IBOC and analog interferers nearly identical; Technics: IBOC interferer degraded performance at -30, -35, -40 dB D/U; Sony: performance with analog sufficiently degraded that IBOC impact not meaningful Subjective: results with IBOC and analog interferers nearly identical
Lab – F/SC.1, F/SC.5 - IBOC ➜ analog (analog FM subcarriers), single 1st adj.	Appendix SCA-A: - Table 2, pg. 8 (67 kHz, McMartin- before repair) - Table 3, pg. 10 (67 kHz, McMartin- after repair) - Table 4, pg. 12 (67 kHz, Norver) - Table 5, pg. 14 (92 kHz, CozmoCom) - Table 6, pg. 16 (92 kHz ComPol)	Appendix SCA-A: - Table 17, pg. 45 Appendix SCA-C, pg. 2	Objective: 67 kHz: results with IBOC and analog interferers nearly identical; 92 kHz: slight impact with CozmoCom (1.5-4 dB) due to IBOC interferer in +16 dB D/U case (no noise); this impact masked by 30,000K noise. Subjective: 67 kHz: audio quality reduced when IBOC interferer present (*e.g.*, fair to poor); 92 kHz: audio quality bad to poor with or without IBOC.

Lab – F/SC.2, F/SC.6 - IBOC ➜ analog (analog FM subcarriers), single 2nd adj.	Appendix SCA-A: - Table 2, pg. 8 (67 kHz, McMartin- before repair) - Table 3, pg. 10 (67 kHz, McMartin- after repair) - Table 4, pg. 12 (67 kHz, Norver) - Table 5, pg. 14 (92 kHz, CozmoCom) - Table 6, pg. 16 (92 kHz ComPol)	Appendix SCA-A: - Table 17, pg. 45 Appendix SCA-C, pg. 3	Objective: 67 kHz: McMartin receiver fails with IBOC interferer at –30 dB D/U; Norver receiver fails with both IBOC, analog interferers at -20 dB D/U 92 kHz: CozmoCom receiver S/N reduced 3-15 dB by IBOC interferer at -20 dB D/U; ComPol reduced 14-21 dB by IBOC interferer at -20 dB D/U. Subjective: 67 kHz: McMartin audio quality goes from fair to bad when IBOC interferer present for -30 dB D/U; 92 kHz: receivers fail with IBOC interferer at -30 dB D/U but audio quality was bad to poor with analog interferer.
Lab – F/SC.3 - IBOC ➜ analog (digital FM subcarriers), single 1st adj.	Appendix SCA-A: - Table 7, pg. 18 (RDS) - Table 8, pg. 20 (DARC)	n/a	Results with IBOC and analog interferers identical for RDS, nearly identical for DARC.
Lab – F/SC.4 - IBOC ➜ analog (digital FM subcarriers), single 2nd adj.	Appendix SCA-A: - Table 7, pg. 18 (RDS) - Table 8, pg. 20 (DARC)	n/a	Results with IBOC and analog interferers identical for RDS, nearly identical for DARC.
Lab – G.1 - IBOC ➜ analog (main channel audio) with multipath, single 1st adj.	n/a	Appendix D: - Table 10, pg. 21 Appendix I, pg. 32-33	Subjective: Delphi, Pioneer: IBOC interferer degraded performance at +6 dB D/U, impact most significant for speech programming; Technics, Sony: n/a (mobile receivers only)
Field – C.3 – 1st adjacent compatibility	Appendix F9: - Pg. 3 (WETA locations) - Pg. 4 (WETA differential field intensity map) - Pg. 5 (WPOC locations) - Pg. 6 (WPOC differential field intensity map) - Pg. 7 (WNEW locations) - Pg. 8 (WNEW differential field intensity map)	Main report: - Fig. 27, pg. 42 - Fig. 28, pg. 43 - Fig. 29, pg. 44 - Fig. 30, pg. 45 - Table 7, pgs. 49-50 - Fig. 34, pg. 51 - Fig. 35, pg. 52 Appendix I: - Pg. 18 - Pg. 20 (with multipath) Appendix N	Objective: Longley-Rice predicted maps suggest only scattered small spots of IBOC impact in areas where good analog reception should now be possible. Subjective: Delphi, Sony: IBOC interferer degraded analog audio quality across all programming formats to some degree, but not to point that at least half of listeners would tune away; Pioneer, Technics: IBOC interferer degraded analog audio quality across all programming formats to some degree, but with the exception of speech programming not to the point that at least half of listeners would tune away; iBiquity reports no complaints from anyone (listeners, broadcasters, etc.) about degraded analog audio quality throughout entire field test program.

The data from the NRSC's FM IBOC compatibility tests seems to indicate that listeners were more critical of interference at a particular D/U ratio when the results came from the laboratory than when they came from the field. Additional information on this is provided in Appendix H of this report.

4.12.1 Co-channel compatibility

Introduction of hybrid FM IBOC should not add additional co-channel interference into the FM band. This is due to the fact that the power level of the analog portion of an interfering IBOC signal is 20 dB greater than that in the IBOC digital sidebands, and also to the fact that the analog portion of the interferer is frequency coincident with the analog portion of the desired signal, while the IBOC digital sidebands are in effect adjacent to the analog portion of the desired signal. Because this performance is dictated by design, the NRSC test procedures do not include tests for co-channel compatibility.

4.12.2 1st-adjacent channel compatibility

The digital sidebands in iBiquity's FM IBOC system occupy a portion of the spectrum used by the analog signals of the two first adjacent channel stations (as illustrated in Figure 2 above). That is, one of the digital sidebands for a particular FM IBOC station occupies a portion of the same spectrum used by an analog signal that is one channel below it, and the other digital sideband for the IBOC station occupies a part of the same spectrum used by the analog station that is one channel above it. As a result, first adjacent channel compatibility is one of the more significant challenges for the FM-band IBOC system.

In order to control first adjacent channel interference in the all-analog environment today, the FCC will only permit a new or modified FM station to go on the air if the new station will produce a signal at least 6 dB weaker than the signal of any nearby first adjacent channel station at the protected contour of the nearby first adjacent channel.

When analyzing the compatibility data that was collected during the NRSC's FM IBOC test program, a basic distinction was made between FM IBOC's impact inside the protected contours of existing analog stations versus its impact outside these protected contours, with the NRSC electing to focus on the area inside the protected contour. The NRSC is cognizant, however, that FM IBOC will potentially have an impact on analog listening beyond the protected contour, and for the broadcasters, receiver manufacturers and listeners to whom this is important an analysis of this impact is also provided.

4.12.2.1 1st-adjacent channel compatibility – inside the protected contour

The test program measured the performance of analog receivers when subjected to first adjacent channel FM IBOC signals at specific desired-to-undesired signal (D/U) ratios. Laboratory measurements were taken at 10 dB D/U intervals from +16 dB D/U to -24 dB D/U. Field measurements were taken at various D/U ratios from +6 dB D/U to -14 dB D/U. This test method allows the D/U ratio at which the FM IBOC signal will interfere with first adjacent channel analog reception to be identified within a specific range of D/U values for each test condition.

Included in the FM Test Data Report are the results of a subjective listening experiment in which typical radio listeners rated the audio quality of various audio segments, and also indicated whether or not they would continue listening to a station with that level of audio quality.[22] The results of this experiment provide the point, in terms of audio quality defined by an absolute quality rating mean opinion score (ACR-MOS) ranging from one to five, at which half the listeners stopped listening to a station for three types of programming (classical, rock and speech). Instead of five integer numbers, the listeners were asked to choose from among five adjectives (excellent, good, fair, poor and bad) when rating the audio. When converted to numerical values for analysis these adjectives were assigned the values five, four, three, two and one, respectively. The ACR-MOS scores where half the listeners stopped listening to the three types of program material are presented in Table 19.

[22] FM IBOC Test Data Report, Appendix J.

Table 19: Tune-out point for different types of programming

TYPE OF PROGRAMMING	AUDIO QUALITY AT AND BELOW WHICH HALF OF LISTENERS WOULD NOT LISTEN (ACR-MOS SCORE)
Classical	2.1
Rock	2.0
Speech	2.3

In addition to subjective ratings for audio samples from both the laboratory and the field, objective measurements of audio signal-to-noise levels were performed during laboratory tests. When one compares the D/U ratios where the subjectively rated tune-out points occurred in the iBiquity test report with the D/U ratios where the objectively measured 30 dB WQP S/N ratios occurred in the iBiquity test report, there is strong correlation. Thus, it appears that 30 dB WQP as measured on the test platform is the S/N ratio below which listeners will not listen to analog FM radio.

Using the subjectively-rated tune-out points listed in Table 19, and the 30 dB WQP S/N ratio objective criteria, the bounds within which tune-out occurs under each test condition can be determined from the FM IBOC test results. To determine these bounds, the two D/U ratios between which received analog FM audio quality in the presence of first adjacent channel FM IBOC signals went from above the tune-out point to at or below the tune-out point must be identified. Then, analog reception in the presence of first adjacent channel analog signals at these two D/U ratios must be compared with analog reception in the presence of FM IBOC signals at these D/U ratios. If there is no significant difference between the analog audio quality in the presence of first adjacent analog signals at both D/U ratios, and the analog audio quality in the presence of first adjacent FM IBOC signals at both D/U ratios, then it is reasonable to conclude that the introduction of FM IBOC would not have any significant impact under the given test conditions. However, if there is a significant difference between the analog audio quality in the presence of first adjacent analog signals at one or both of the D/U ratios, and the analog audio quality in the presence of first adjacent FM IBOC signals at one or both of the D/U ratios, then it is reasonable to conclude that the introduction of FM IBOC would have an impact under the given test conditions.

Employing this logic, testing was conducted that was designed to stress the system and find the points at which there was a potential for interference from the FM IBOC system. It was found that 20 out of 82 tests suggested a potential impact inside the protected contour.[23] Of the 20 tests that showed a potential for new interference inside the protected contour, 16 were laboratory tests. It is believed that the analog audio samples recorded in the laboratory were judged more critically by the listeners than were the samples recorded in the field because the automobile receivers were operating in stereo when the samples in the laboratory were recorded, and in mono when most of the samples in the field were recorded, and interference is more noticeable during stereophonic reception than it is during monophonic reception. Stereo reception occurred in the lab while mono reception occurred in the field because the receiver input signal level used in the laboratory was significantly higher than the receiver input signal level for many of the field tests, and at the lower receiver input signal levels the automobile receivers automatically switch to monophonic reception to reduce audible noise. Thus, one might expect the laboratory results to be more indicative of listener reaction when a pair of first adjacent stations are short-spaced and thus producing strong desired and undesired signal levels for listeners, a relatively infrequent occurrence. The

[23] Based on field test results, and laboratory results with 30,000K AWGN RF noise – see Section 4 above for additional information on use of 30,000K AWGN.

field tests, on the other hand, are believed to be more indicative of the typical first adjacent channel spacings that exist in the FM band.

Focusing on the field test data, only 4 of 18 tests would suggest the potential for new interference inside the protected contour. And, of these four tests, only one produced results with a confidence interval that indicates at least fifty percent of listeners would stop listening to the station due to the interference from the first adjacent IBOC station. These field test results are summarized in Table 20.

Table 20: Summary of 1st-adjacent FM IBOC impact inside protected contour

	FIELD TESTS	
RECEIVER TYPE	TOTAL	SHOWING NEW INTERFERENCE INSIDE PROTECTED CONTOUR THAT WOULD CAUSE AT LEAST HALF OF LISTENERS TO TUNE OUT
OEM auto	6	0
Aftermarket auto	6	0
Home hi-fi	3	1
Portable	3	0

Based on the results summarized in Table 20 it appears that the introduction of FM IBOC will have no significant impact inside the protected contours of FM radio stations.

4.12.2.2 1st-adjacent channel compatibility – outside the protected contour

The area beyond the protected contour requires a different type of analysis than the area within the protected contour because beyond the protected contour the question is not if there will be new interference, but rather how much. Stations are expected to receive interference beyond the protected contour even with the analog FM transmissions of today. To determine how much new interference might occur to analog reception with the introduction of FM IBOC, data was collected at a number of D/U ratios that occur beyond the protected contour.

Laboratory and field data was collected for 12 D/U ratios typically found outside the protected contour. The majority of this data was collected for the automobile receivers. There was a limited amount of data collected for the home hi-fi and portable receivers, and it served to confirm that these receivers are generally not capable of producing acceptable levels of audio quality when located beyond the desired station's protected contour due to analog first adjacent channel interference. Since there would in that case be no additional impact due to FM IBOC (from the listener's perspective), the data for these receivers is not included in this analysis.

All of the beyond-the-protected contour first adjacent channel data for the automobile receivers was analyzed and it was found that 21 out of 58 tests suggested that there would be some new interference outside the protected contour.[24] Of the 21 tests that showed some new interference outside the protected contour, 16 were laboratory tests. As discussed above, the receiver input signal level used in the lab for the +6 and -4 dB D/U ratio tests was considerably higher than the receiver input signal levels from many of the field test sites for these D/U ratios. When the field tests alone are considered, only 5 of 34 tests would suggest some new interference outside the protected contour. And, of these five

[24] As with the inside-the-protected contour data, only the results with 30,000K added were used from the laboratory. See footnote 23.

tests, only three produced results with a confidence interval that suggested at least fifty percent of listeners would stop listening to the station due to the interference from the first adjacent IBOC station. These results are summarized in Table 21.

Table 21: Summary of 1st-adjacent FM IBOC impact outside protected contour

D/U Ratio (dB)	Field Tests: Total	Field Tests: Showing new interference outside protected contour that would cause at least half of listeners to tune out
+4	2	0
-1	2	0
-4	6	1
-6	4	0
-8	2	0
-9	6	0
-10	2	0
-11	2	0
-12	2	2
-13	2	0
-14	4	0

It should be noted that, of the 34 first adjacent field tests for the automobile receivers, 24 (or 71%) were collected using rock or country programming as the desired audio. Six (or 17%) were collected with speech as the desired audio, and 4 (or 12%) were collected with classical music as the desired audio. Because the test results, in general, indicate that interference at a particular undesired signal level will be more annoying to listeners when the desired programming is speech than when it is rock or country music, it is reasonable to assume that FM IBOC will have a more significant impact on speech programming beyond the protected contour than the data in Table 21 suggest. Any impact from IBOC, however, for speech and other formats is expected to be limited by the fact that there are small geographic areas where listeners experience these levels of first adjacent interference and still receive adequate analog reception. Moreover, because any potential impact from IBOC will be limited to automobile receivers, the impact should be further reduced by the fact that the listener is mobile and will move through any areas of interference. As the D/U ratio changes dynamically with the movement of the automobile, any IBOC impact may quickly disappear.

It should also be noted that the perceived audio quality from the automobile receivers did not steadily decline as the interfering signal got stronger. There are several cases in the data where increasing the strength of the interfering signal actually improved the rating that the listeners gave to the desired audio. This is likely because automobile receivers are competitively designed for harsh reception conditions and, as interfering signals get stronger, circuitry inside these radios activates to perform functions such as switching to monophonic reception or narrowing the receiver's intermediate frequency bandwidth to better block out the interference. Laboratory testing by the NRSC subsequent to the release of the iBiquity FM IBOC test report has found that this sort of circuitry will activate in automobile receivers in the presence of strong interfering signals on second, fifth, tenth and twentieth adjacent channels. This is undoubtedly because this type of interference can occur anywhere within a station's listening area, and receiver manufacturers want their products to perform well throughout this area. This suggests that the introduction of FM IBOC may, in many cases, cause mobile analog reception outside the protected contour to become more monophonic than it is now. However, it is important to note that listeners today frequently receive a monophonic signal, even within the protected contour, and are satisfied with that analog reception. In many cases, listeners prefer unimpaired monophonic reception when compared to impaired stereo signals. Therefore, it can be assumed that the introduction of IBOC and any increase in monophonic reception will not degrade the listening experience in the majority of cases.

It appears that the introduction of FM IBOC will, in certain cases, have some negative impact on analog reception outside the protected contours of FM radio stations. This impact is most likely to be perceptible when the desired analog FM programming is primarily speech. Also, it is only expected to affect automobile receivers because home hi-fi and portable receivers are generally not capable of receiving good audio in the presence of first adjacent channel analog signals beyond the protected contour today. Moreover, because the level of severe first adjacent interference required for any IBOC impact is limited geographically to small areas, any potential impact will be further limited. It appears that the introduction of IBOC will not degrade the listening experience in the majority of cases.

4.12.2.3 NRSC Study on 1st-adjacent channel interference

To illustrate how one might go about predicting where potential areas of new interference might occur in an analog FM station's coverage area with the introduction of a first adjacent channel FM IBOC signal, the NRSC commissioned a study by the engineering consulting firm Denny & Associates, P.C., and TechWare, Inc., a software contractor with extensive experience predicting interference associated with the rollout of digital television. The study results are in Appendix I.

This study cannot be used to make general conclusions about the amount of interference that might occur with the introduction of FM IBOC because only six stations were studied. Furthermore, for the six stations that were studied it is not expected that all listeners in the areas where new interference is predicted would tune away from the desired analog station because of the interference. The subjective ratings of audio quality that were the basis for picking the D/U ratios at which new interference might occur are indicative of only half of all listeners finding the new interference so objectionable that they would tune away. Thus, the interference areas indicated in the study are really predicting areas where, at most, half of all listeners might be inclined to tune away. And, in some portions of these interference areas, the predicted impact would be on fewer than half of all listeners because the subjective evaluation results on which the predictions are based indicated that fewer than half of all listeners found that level of interference objectionable.

While the areas of interference predicted by the study may tend to overstate the potential impact of FM IBOC as just described, in some respects they may also understate it. The study assumes that the impact of FM IBOC on first adjacent analog stations will not be noticed at D/U ratios lower (*i.e.*, more negative) than -4 dB because it is assumed that analog reception at these locations is already impaired. Based on the field test data for speech programming, this appears to be an accurate assumption. However, speech programming samples were only collected at fixed locations in the field. Mobile field test results, which are arguably more illustrative of the performance of automobile radios, were only conducted for rock/country programming. These results indicate that both automobile radios produced audio that was acceptable to most listeners at the -12 dB D/U ratio when the undesired signal was analog, but unacceptable to most listeners when the undesired signal was FM IBOC. Thus, in the case of rock/country programming, the study results in Appendix I predict no interference in some areas where the test data suggests new interference may actually occur (*e.g.*, at the -12 dB D/U ratio). It should be noted, however, that while the +6 dB to -4 dB D/U criteria used to predict interference in the study causes the impact on rock/country programming at -12 dB to be missed, it also greatly exaggerates the impact on rock/country programming within the +6 dB to -4 dB D/U range because, within this range, the subjective test results indicate that listeners are less likely to find the impact of FM IBOC on rock/country programming to be objectionable than they are to find its impact on speech programming objectionable.

Overall, it is extremely difficult to produce a simple, set methodology that can easily be applied to all stations for predicting FM IBOC's impact on first adjacent channel analog reception. The impact that FM IBOC will have is very dependent on the type of receiver that is assumed, and on the programming being broadcast on the desired analog station. Furthermore, as discussed in Appendix I the strength of the two signals involved also plays an important role. It appears that when the two stations are closely spaced, and thus their signals are strong, automobile receivers are more likely to be operating in the stereo mode and listeners are therefore more likely to find first adjacent FM IBOC interference objectionable. However, when the two stations are farther apart and thus their signals are weaker, automobile receivers are more likely to be operating in the monophonic mode and listeners are therefore less likely to find first adjacent FM IBOC interference objectionable. To predict with any degree of confidence the amount of new interference that listeners of any particular FM station might experience as a result of the introduction of FM IBOC, all of these factors must be taken into account.

4.12.3 2nd-adjacent channel compatibility

The NRSC test program included tests to determine the impact of a 2nd-adjacent channel FM IBOC signal on an analog signal. As in previously discussed compatibility tests, the procedure here was to measure the S/N ratio in the main channel audio portion of an analog FM signal, first with an analog interferer, then with a hybrid FM IBOC interferer, and then to subjectively evaluate audio recordings made under these conditions.

The data from the (objective) S/N measurements for all four analog receivers are presented in Figure 20. In the top two graphs, data obtained on the automotive receivers is shown, indicating that these receivers were not impacted by the presence of the IBOC digital sidebands on the 2nd-adjacent channel interferer. This is most likely due to the fact that the automotive receivers have very selective front-end IF filters which eliminated the 2nd-adjacent channel interference.

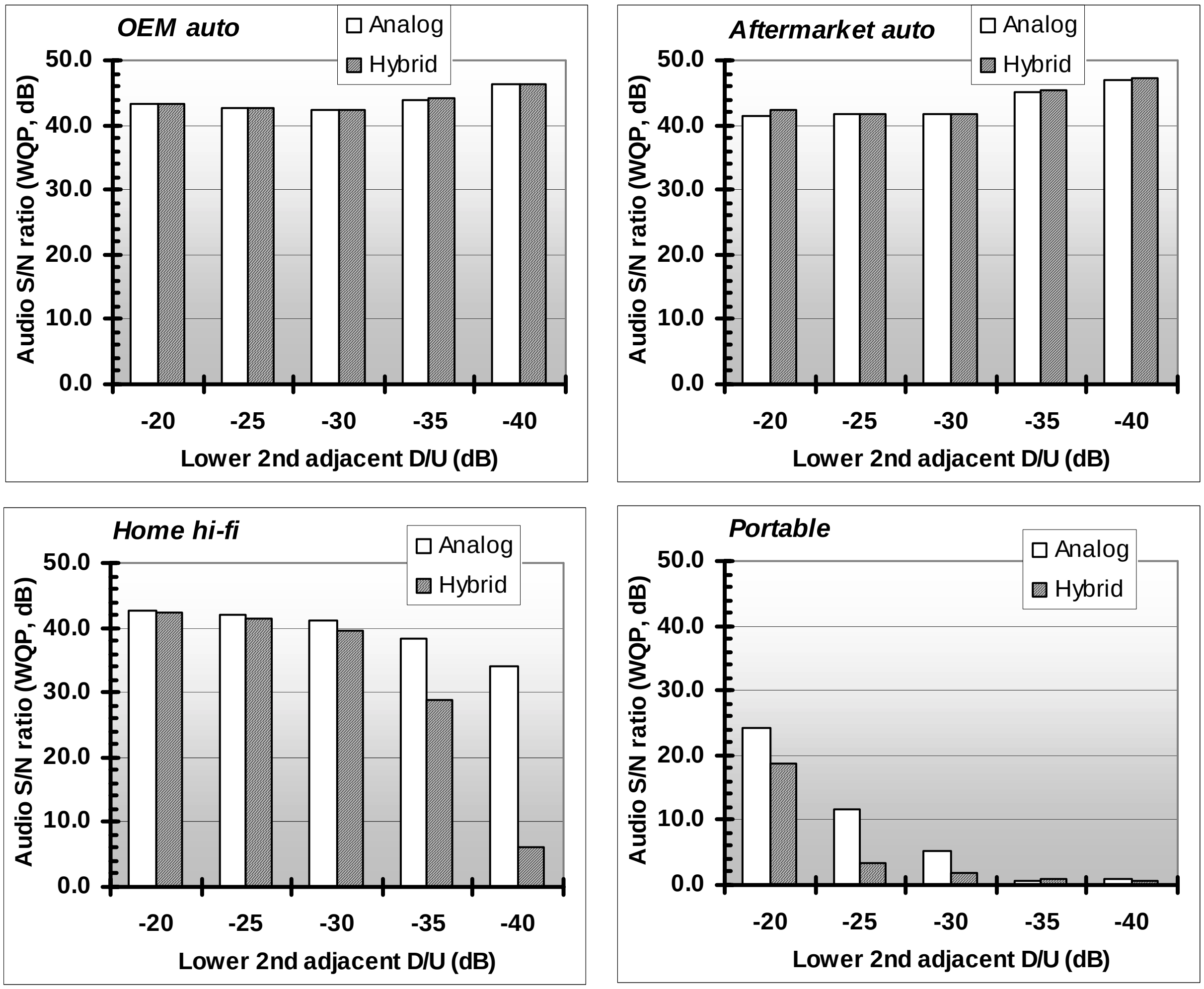

Figure 20. 2nd-adjacent compatibility – objective test results with analog and hybrid interferers (lower 2nd-adj., with 30,000K noise)

The graph in Figure 20 on the lower right shows that for the home hi-fi receiver, as the level of the 2nd-adjacent channel interferer was increased, there was some impact on the desired analog audio signal due to FM IBOC. In particular, at D/U ratios of -35 dB and -40 dB, the S/N ratio in the desired main channel audio was reduced by 10 dB and 28 dB, respectively, with respect to the S/N ratio achieved when an analog (i.e. non-hybrid IBOC) interferer was present. The subjective results for this receiver are shown in Figure 21, where in the -40 dB case the audio quality in the desired analog signal is reduced from “fair” to “bad.”

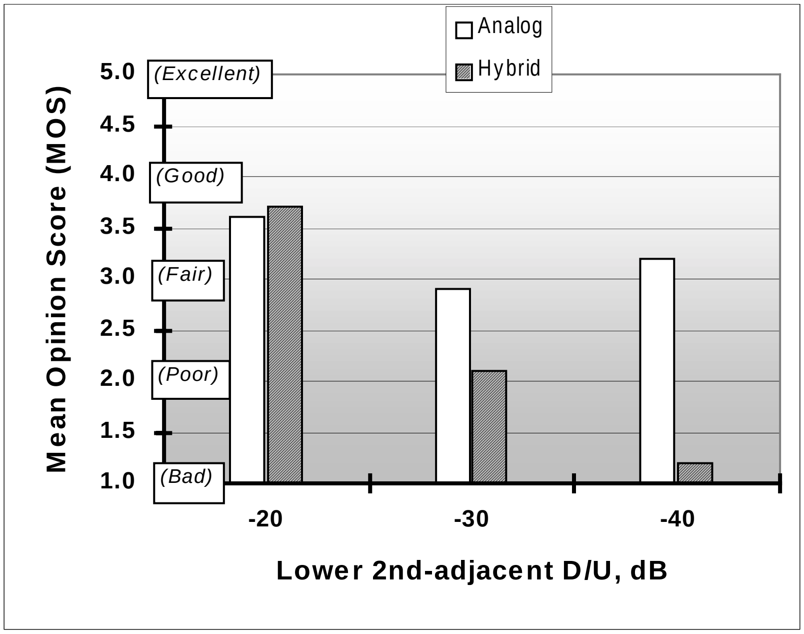

Figure 21. 2nd-adjacent compatibility – subjective test results with analog and hybrid interferers (home hi-fi receiver, lower 2nd-adj., with 30,000K noise)

There are a number of reasons why the hi-fi receiver results presented here are of less concern than the 1st-adjacent channel interference results (outside the protected contour) presented in Section 4.12.2.2 above. Because this receiver is stationary, its antenna can be oriented so as to minimize adjacent channel interference problems. In addition, testing done on other hi-fi receivers (see Appendix H) suggests that the hi-fi receiver tested used in the NRSC FM IBOC tests is among the most susceptible to 2nd-adjacent channel interference and that other hi-fi receivers will be affected less.

In the final graph of Figure 20 (in the lower right) for the portable receiver, again some impact due to the presence of the IBOC digital sidebands on the hybrid interferer is noted, however in this case the S/N ratio in the desired main channel audio signal is so low (irrespective of whether the interferer is hybrid FM IBOC or not), the small additional interference due to the FM IBOC digital sidebands is not significant.

4.12.4 Findings

For the three cases considered, the following findings apply regarding the introduction of hybrid FM IBOC into the FM band:

Co-channel interference: no impact on analog reception (by design).

1st-adjacent channel interference: listeners within the protected contour should not perceive an impact, but a limited number of listeners may perceive an impact outside of the protected contour under certain conditions.

2nd-adjacent channel interference: NRSC tests indicated that some receivers (with performance similar to the NRSC analog automotive and portable receivers) should not experience an impact on performance due to 2nd-adjacent channel hybrid FM IBOC interference, however, a very limited number of receivers (with performance similar to the home hi-fi receiver used in the NRSC tests) might experience a negative impact for -30 to -40 dB (and more negative) D/U ratios.

4.13 Impact on SCA reception

Subcarriers are utilized on slightly less than half of FM stations, according to a 1997 report by NAB.[25] Of particular interest are subcarriers utilized for radio reading services and other audio services operating with analog subcarriers, the RBDS subcarriers delivering station information to consumer receivers so equipped, and data subcarriers, including RBDS and DARC technologies, providing proprietary data services through third parties on a subscription basis.

The NRSC test plan included testing of subcarrier receivers for compatibility with FM IBOC signals on the host and first and second adjacent stations. iBiquity submitted the results of this testing, which included a report on objective test data from the ATTC and a summary of Dynastat subjective testing on lab and field test recordings. The Evaluation Working Group prepared its own detailed evaluation of the results, which is presented in Appendix J.

4.13.1 Findings

In order to evaluate any impact of IBOC on SCA services, the NRSC developed test procedures and witnessed SCA compatibility tests for the IBOC system. Laboratory tests were performed at ATTC and field tests were performed using the facilities of WPOC and experimental station WD2XAB.

The NRSC recognizes that adequate reception of SCA audio is a complex procedure that is very dependent on a host station's operating parameters, distance from transmitter, and adjacent channel signals. In most cases, analog reception of SCA programming is optimized by listeners orienting receiving antennas for best-recovered audio. The limitations of SCA reception are well known to users of analog SCA services and are for the most part accepted and tolerated. It is expected that a new generation of digital technology will be offered by IBOC, with its auxiliary capacity, that will provide significantly improved reception and that existing analog SCA services will over time migrate to them.

During the course of evaluating the various laboratory analog SCA test results, both with and without the addition of IBOC, the NRSC discovered what appear to be significant performance disparities among the receivers used for the tests. In some tests, little or no impact was observed after the introduction of an IBOC signal. However in other tests significant impact was noticed. Similarly in field tests with and without IBOC, some receivers performed well, while others failed totally.

At the time the SCA tests were developed by the NRSC, the DAB Subcommittee felt that the SCA test program would be sufficient to determine conclusively whether or not the adoption of IBOC by FM broadcasters would have an adverse impact on SCA reception. Indeed, careful evaluation of test data shows that the digital SCA services tested (RDS and DARC) should not be adversely impacted by IBOC.

For the case of analog SCA services, some questions still remain as to the impact of IBOC on such services. In order to answer these questions and to provide additional clarity to this matter, iBiquity, National Public Radio and the International Association of Audio Information Services have agreed to expeditiously perform a series of additional tests for the purpose of determining how certain SCA receivers will perform after IBOC is implemented on host and adjacent channel stations. The NRSC

[25] See "NAB FM Subcarrier Market Report/Technology Guide," NAB, 1997, pg. 48.

encourages the rapid completion of these tests in time to provide meaningful input to the FCC for its consideration.

4.14 Industry subjective evaluation

In order to ensure that radio broadcasters have a part in the direct subjective evaluation of IBOC test data, the NRSC worked with iBiquity to develop and conduct an Industry Evaluation. The evaluation was conducted September 5-7, 2001 at the NAB Radio Show in New Orleans.

A total of 61 volunteers from the radio broadcast industry participated in the program. Participants were chosen from a list of volunteers recruited by the NAB through direct solicitations distributed via the Web, email and print.

The methodology used in this evaluation followed very closely that used at Dynastat as described earlier in this report. However, Dynastat chose as its participants members of the general public who were not necessarily associated with the radio industry. Audio samples used were obtained from digital recordings representing a variety of relevant laboratory and field tests of the IBOC system.

The results of the Industry Evaluation, for all practical purposes, were the same as those obtained in the Dynastat program, demonstrating that the broadcast industry participants were no more or less affected by the various test audio samples than the participants from the general public.

Data from the Industry Evaluation is attached to this report as Appendix K.

Appendix A –
DAB Subcommittee Goals & Objectives

NATIONAL
RADIO
SYSTEMS
COMMITTEE

DAB Subcommittee
Evaluation of the iBiquity Digital Corporation IBOC System

Part 1 – FM IBOC

Consumer Electronics Association
A sector of EIA

2500 Wilson Boulevard
Arlington, VA 22201-3834
(703) 907-7500
FAX (703) 907-7501

NATIONAL RADIO SYSTEMS COMMITTEE

National Association of Broadcasters

1771 N Street, NW
Washington, DC 20036-2800
(202) 429-5346
FAX (202) 775-4981

6/29/00

DAB Subcommittee

Goals & Objectives

(as adopted by the Subcommittee on May 14, 1998)

Objectives

(a) To study IBOC DAB systems and determine if they provide broadcasters and users with:
- A digital signal with significantly greater quality and durability than available from the AM and FM analog systems that presently exist in the United States;
- A digital service area that is at least equivalent to the host station's analog service area while simultaneously providing suitable protection in co-channel and adjacent channel situations;
- A smooth transition from analog to digital services.

(b) To provide broadcasters and receiver manufacturers with the information they need to make an informed decision on the future of digital audio broadcasting in the United States, and if appropriate to foster its implementation.

Goals

To meet its objectives, the Subcommittee will work towards achieving the following goals:

(a) To develop a technical record and, where applicable, draw conclusions that will be useful to the NRSC in the evaluation of IBOC systems;

(b) To provide a direct comparison between IBOC DAB and existing analog broadcasting systems, and between an IBOC signal and its host analog signal, over a wide variation of terrain and under adverse propagation conditions that could be expected to be found throughout the United States;

(c) To fully assess the impact of the IBOC DAB signal upon the existing analog broadcast signals with which they must co-exist;

(d) To develop a testing process and measurement criteria that will produce conclusive, believable and acceptable results, and be of a streamlined nature so as not to impede rapid development of this new technology;

(e) To work closely with IBOC system proponents in the development of their laboratory and field test plans, which will be used to provide the basis for the comparisons mentioned in Goals (a) and (b);

(f) To indirectly participate in the test process, by assisting in selection of (one or more) independent testing agencies, or by closely observing proponent-conducted tests, to insure that the testing as defined under Goal (e) is executed in a thorough, fair and impartial manner.

Appendix B –
IBOC laboratory test procedures – FM band

NATIONAL
RADIO
SYSTEMS
COMMITTEE

DAB Subcommittee
Evaluation of the iBiquity Digital Corporation IBOC System

Part 1 – FM IBOC

IBOC LABORATORY TEST PROCEDURES – FM BAND
OVERALL COMMENTS

1. The test laboratory (ATTC) will provide a detailed certification of the test bed.
2. Appendix A is a list of the test results (resulting from these procedures) which must be included in the laboratory test record to be provided to the NRSC at the conclusion of testing. Note that this list is not meant to suggest the format in which those results are to be presented in that record, but is simply an enumeration of those results.
3. IBOC receiver point-of-blend is established by the "mode" signal which is supplied by the receiver. IBOC receiver block error rate (BLER) is also observable.
4. Unless otherwise specified, the audio selections to be used as source material for desired and interfering channels are specified in the NRSC audio test list, and, the source audio for analog reference recordings will be the same as that used for the corresponding IBOC digital audio recordings.
5. The following three RF composite signal levels are used in the FM laboratory tests:

DESIGNATION	DESCRIPTION	LEVEL (DBM)
M	Moderate	-62
S	Strong	-47
W	Weak	-77

6. Digital recordings of analog and IBOC digital audio indicated by these procedures are for archival and/or subjective evaluation purposes. All such recordings will be made in the following format: uncompressed linear 16-bit digital audio sampled at 44.1 kHz, and will be suitable for transfer to CD to facilitate further analysis.
7. Multipath scenarios used in these tests will be the same scenarios used in the EIA DAR laboratory tests conducted in 1995, utilizing nine desired signal paths (rays) and six undesired paths, as specified in Appendix E of the August 11, 1995 report ("VHF Rayleigh 9-path simulation").
8. The detailed procedure for RF noise measurements will be supplied. See Appendix S of the EIA DAR Laboratory Tests Report, August 11, 1995.
9. For tests involving use of the multipath simulator, the RF level will be characterized according to the procedure described in the ATTC report "The Measurement of Power as applied to IBOC DAB signals in the Presence of Multipath for the FM-band," Document #00-02 November 16, 2000.
10. Unless otherwise specified, IBOC transmitters will be used to generate undesired signals in co- and adjacent-channel interference tests.

IBOC LABORATORY TEST PROCEDURES – FM BAND
OVERALL COMMENTS (continued)

11. Unless otherwise specified, analog audio (as opposed to IBOC digital audio) signal power meas. will be made using the weighted quasi-peak ("WQP," CCIR weighting filter) measurement technique. Analog audio noise measurements will in addition use a 19 kHz lowpass pilot filter.
12. The host FM to digital power ratio used in the digital performance tests will also be used for the analog compatibility tests.
13. The following four subcarrier configurations are used in the FM laboratory analog compatibility tests (see test groups F, J):

		INJECTION LEVEL			
Description	Center frequency (kHz)	Config. #1	Config. #2	Config. #3	Config. #4
*Main channel audio	N/A	80%	85%	85%	80%
Stereo pilot	19.0	10%	10%	10%	10%
RDS digital subcarrier	57.0	3%	10%	-	-
"High speed" digital subcarrier (HSSC)	76.0	-	-	10%	-
**Analog audio subcarrier – FM modulated, ± 5 kHz peak deviation, 150 µsec pre-emphasis	67.0	8.5%	-	-	10%
**Analog audio subcarrier – FM modulated, ± 5 kHz peak deviation, 150 µsec pre-emphasis	92.0	8.5%	-	-	10%
TOTAL subcarrier injection		20%	10%	10%	20%
TOTAL injection (main channel and subcarriers)		110%	105%	105%	110%

* Main channel audio modulated with audio cuts from NRSC Audio Test List for subjective evaluations or 1 kHz tone for S/N measurements

**Analog subcarriers modulated with USASI noise except for subjective evaluations (TBD audio) or S/N measurements (400 Hz tone). When the same audio cuts are used for 67 and 92 kHz subcarriers, they will be offset in time by TBD sec (to de-correlate).

14. Unless otherwise indicated, interfering signals will not utilize any subcarriers other than the stereo pilot and L-R signal.
15. For tests involving multipath fading, point-of-blend will be determined utilizing the procedure described in the memo from G. Nease (iBiquity) to Andy Laird (TPWG chairman), dated November 28, 2000, and entitled "Method for the Determination of Point-of-Blend in Multipath Conditions."
16. NRSC analog test receivers specified on pg. 16 will undergo the following characterization tests: [list TBD]
17. [definition of clipped pink noise to be added here]

IBOC LABORATORY TEST PROCEDURES – FM BAND
CALIBRATION

Test Group	Test & Impairment	TEST DESCRIPTION Note: 1. One impairment audio cut will be selected from the NRSC Audio Test List for point of blend tests for calibration.	Desired Signal Level	Type of Evaluation	Test Results Data to be Recorded
A Calibration	1 Power	1. IBOC analog and digital average power will be measured separately (as needed). 2. The digital-only average and peak power will be measured at least once.	NA	Objective	Analog average power level Digital average and peak power levels
	2 Spectrum (each test day or as needed)	1. A spectrum analyzer plot of the system RF spectrum will be taken for each test day (or as needed). 2. The spectrum analyzer settings will be: RES BW 1 kHz, VBW 30 Hz, and sweep span of 500 kHz.	M	Objective	Spectrum plot
	3 Point of blend (as needed)	1. Gaussian noise will be added to the signal in 0.20 dB steps until point of blend is detected (using mode signal), or block error equivalent to point of blend is observed.	M	Objective	Noise level, BLER at point of blend
	4 Analog host proof-of-performance	1. During the analog compatibility tests, a proof of performance test will be conducted on the analog host portion of the IBOC system. A high quality demodulator will be used for this test.	Varying	Objective	Frequency response, L&R separation, audio SNR, and audio THD
	5 Monitor calibration (as needed)	1. The analog modulation monitors will be calibrated. Bessel null is the recommended method for calibration. Settings for the Belar Wizard modulation monitor will be: Hold 1.0 sec; Peak Mod 100.5%; Infinite off; Blank off; Resolution 0.1%; Time Mode past; Pk Weight 9 cyc; ppm duration 100 ms; ppm threshold 10.	NA	Objective	Calibration results
	6 Test bed calibration (prior to test)	1. All of the critical components in the test bed, including the multipath simulator, attenuators, combiners, filters, generators, and measuring instruments, will be certified by the testing laboratory prior to tests.	NA	Objective	Calibration results

IBOC LABORATORY TEST PROCEDURES – FM BAND
DIGITAL PERFORMANCE

Test Group	Test & Impairment	TEST DESCRIPTION Notes: 1. For urban slow multipath tests, the desired multipath audio selections will be repeated as required to complete a full fading cycle on the MP simulator. 2. The audio will be restarted for each test. 3. The analog reference recordings specified in step B.2.5 will be made with the IBOC digital sidebands removed from the desired signals.	Desired Signal Level	Type of Evaluation	Test Results Data to be Recorded
B AWGN	1 Linear channel	1. The level of AWGN corresponding to system point of blend will be established. 2. The desired impairment audio segments will be recorded with the AWGN set at a level 2 dB below (i.e. before) the point of blend. 3. The BLER will be recorded with the AWGN set at a level 4 dB below (i.e. before) the point of blend, then with the AWGN level increased in 1 dB steps until at the point of blend, then at 2 dB and 4 dB above (i.e. after) the point of blend.	M	Objective	Cd/No, BLER for each measurement point (with point of blend identified)
				Subjective	Subjective impairment rating for recording made in step 2
	2 Multipath fading channel	1. This test will be conducted four times, each with a different Rayleigh multipath scenario. The multipath scenarios will be those specified on the "general comments" page of this procedure. Each cut will be recorded for subjective assessment. 2. For each multipath scenario, the level of AWGN corresponding to system point of blend will be established. 3. The desired impairment audio segments will be recorded with the AWGN set at a level 8 dB below (i.e. before) the point of blend. 4. The BLER will be recorded with the AWGN set at a level 8 dB below (i.e. before) the point of blend, then with the AWGN level increased in 2 dB steps until 6 dB above (i.e. after) the point of blend. 5. An analog reference recording will be made using NRSC analog test receivers #1 and #2 (automobile receivers) for each multipath scenario, at the measurement point of step 3.	M	Objective	Cd/No, BLER for each measurement point (with point of blend identified)
				Subjective	Subjective impairment rating for each multipath scenario and audio cut, for IBOC digital and analog reference recordings made in steps 2 and 5

IBOC LABORATORY TEST PROCEDURES – FM BAND
DIGITAL PERFORMANCE

Test Group	Test & Impairment	TEST DESCRIPTION	Desired Signal Level	Type of Evaluation	Test Results Data to be Recorded
		Notes: 1. Desired audio cut used for these tests will be the desired impairment audio classical music selection; undesired audio cut will be the first adjacent impairment audio. 2. Each test will last no more than 30 seconds. 3. The audio will be restarted for each test. 4. The analog reference recordings specified in each step will be made with the IBOC digital sidebands removed from the desired and undesired signals. 5. For test C.1, only those sets of recordings corresponding to pulse frequencies of 120 Hz, and those closest to 500 Hz and 1500 Hz, will be subjectively evaluated.			
C IBOC with special impairments	1 Impulse noise	1. An RF pulse generator capable of RF pulses with a rise and decay time of at least 3 to 4 nanoseconds will be used for this test. The pulse generator output will be combined with the hybrid IBOC RF signal, and the RF pulse peak power level will be 30 dB above that of the unmodulated analog carrier. 2. IBOC digital audio will be recorded for one minute each, for six pulse rates between 100 Hz to 2000 Hz. 120 Hz pulse rate will be included in all the tests. The center frequency of the RF pulse should be the center frequency of the desired channel. 3. For each measurement point, the mode signal status will be recorded. 4. Steps 2 and 3 will be repeated using a random pulse repetition frequency (PRF) impulse noise source. 5. Steps 2-4 will be repeated using a single lower first adjacent undesired signal. The D/U ratio will be set for +6 dB. 6. An analog reference recording will be made using NRSC analog test receivers #1 and #2 (automobile receivers) for each impulse noise scenario described in steps 2-5.	M	Objective	Mode signal status for each measurement point
				Subjective	Subjective impairment rating for each pulse rate, amplitude and interference scenario for IBOC digital and analog reference recordings
	2 Airplane flutter (Doppler)	1. Tests will be conducted for three simulated aircraft speeds and MP delay scenarios: a. 400 Km/h, main signal attenuation 0 dB, reflection delay 27.5 µsec, attenuation 8 dB b. 200 Km/h, main signal attenuation 0 dB, reflection delay 18.7 µsec, attenuation 6 dB c. 100 Km/h, main signal attenuation 0 dB, reflection delay 6.8 µsec, attenuation 4 dB 2. A 30 second impairment recording will be made for each scenario. 3. For each measurement point, the mode signal status will be recorded. 4. Steps 1 and 2 will be repeated with a single lower first adjacent undesired signal. The D/U ratio will be set for +6 dB. 5. An analog reference recording will be made using NRSC analog test receivers #3 and #4 (non-automobile receivers) for each airplane flutter scenario described in steps 1-4.	M	Objective	Mode signal status for each measurement point
				Subjective	Subjective impairment rating for each airplane flutter scenario for IBOC digital and analog reference recordings

IBOC LABORATORY TEST PROCEDURES – FM BAND
DIGITAL PERFORMANCE

Test Group	Test and Impairment	TEST DESCRIPTION	Desired Signal Level	Type of Evaluation	Test Results & Data to be Recorded
		Notes: 1. All interferers are to be hybrid IBOC signals – refer to NRSC Audio Test List for information on interferer modulation. 2. The analog reference recordings specified in each step will be made with the IBOC digital sidebands removed from the desired and undesired signals. 3. For tests D.2 and D.3, analog reference recordings will be made with all relevant permutations of upper/lower adjacent channel interference. 4. The analog reference recordings specified in each step will be made with the IBOC digital sidebands removed from the desired and undesired signals.			
D IBOC ➜ IBOC	1 Co-channel	1. The co-channel D/U corresponding to system point of blend will be established. 2. The desired impairment audio segments will be recorded with the co-channel D/U set at a level 2 dB below (i.e. before) the point of blend. 3. For each measurement point, the mode signal status will be recorded. The BLER will be recorded with the co-channel D/U set at a level 2 dB below (i.e. before) the point of blend, then with the co-channel level increased in 1 dB steps until 1 dB above (i.e. after) the point of blend. 4. An analog reference recording will be made using NRSC analog test receivers #2 and #3 for the measurement point of step 2.	M	Objective	Co-channel D/U, BLER, mode signal for each measurement point
				Subjective	Subjective impairment rating for IBOC digital and analog reference recordings made in steps 2, 4
	2 Single and dual 1st adjacent	1. Using a lower 1st adjacent channel interferer, the D/U corresponding to system point of blend will be established. 2. The desired impairment audio segments will be recorded with the lower 1st adj. chan. D/U set at a level 2 dB below (i.e. before) the point of blend. 3. For each measurement point, the mode signal status will be recorded. The BLER will be recorded with the lower 1st adj. chan D/U set at a level 2 dB below (i.e. before) the point of blend, then with the 1st adj. chan. level increased in 1 dB steps until 1 dB above (i.e. after) the point of blend. 4. Steps 1-3 will be repeated with the addition of an upper 1st adj. chan. interferer at 6 dB D/U. 5. An analog reference recording will be made using all 4 NRSC analog test receivers for the measurement point 2 dB below (i.e. before) the point of blend.	M	Objective	1st adj. channel D/U, BLER, mode signal status for each measurement point
				Subjective	Subjective impairment rating for IBOC digital and analog reference recordings made in steps 2, 4, and 5

(continued on next page)

(continued from last page)

IBOC LABORATORY TEST PROCEDURES – FM BAND DIGITAL PERFORMANCE					
Test Group	Test and Impairment	TEST DESCRIPTION Notes: 1. All interferers are to be hybrid IBOC signals – refer to NRSC Audio Test List for information on interferer modulation. 2. The analog reference recordings specified in each step will be made with the IBOC digital sidebands removed from the desired and undesired signals. 3. For tests D.2 and D.3, analog reference recordings will be made with all relevant permutations of upper/lower adjacent channel interference. 4. The analog reference recordings specified in each step will be made with the IBOC digital sidebands removed from the desired and undesired signals.	Desired Signal Level	Type of Evaluation	Test Results & Data to be Recorded
D IBOC ➜ IBOC	3 Single and dual 2nd adjacent, and simultaneous single 2nd and single 1st adjacent	1. Using a lower 2nd adjacent channel interferer, the D/U corresponding to system point of blend will be established. 2. The desired impairment audio segments will be recorded with the lower 2nd adj. chan. D/U set at a level 2 dB below (i.e. before) the point of blend. 3. For each measurement point, the mode signal status will be recorded. The BLER will be recorded with the lower 1st adj. chan D/U set at a level 2 dB below (i.e. before) the point of blend, then with the 1st adj. chan. level increased in 1 dB steps until 1 dB above (i.e. after) the point of blend. 4. Steps 1-3 will be repeated with the addition of an upper 1st adj. chan. interferer at 6 dB D/U. 5. Simultaneous upper and lower 2nd adj. chan. tests will be conducted using the D/U setting in step 2 for the lower interferer and with the upper interferer fixed at –20 dB D/U. 6. An analog reference recording will be made using NRSC analog test receivers #3 and #4 (non-automobile receivers) for the measurement point 2 dB below (i.e. before) the point of blend.	M	Objective	2nd adj. channel D/U, BLER, mode signal status for each measurement point
				Subjective	Subjective impairment rating for IBOC digital and analog reference recordings made in steps 2, 4, 5, and 6

IBOC LABORATORY TEST PROCEDURES – FM BAND
DIGITAL PERFORMANCE

Test Group	Test and Impairment	TEST DESCRIPTION	Desired Signal Level	Type of Evaluation	Test Results & Data to be Recorded
		Notes: 1. Each undesired channel will be modulated with the multipath interference selection. When there are two undesired channels, the audio cuts and multipath conditions will be time shifted with respect to one another by TBD ms (for audio) and TBD ms (for multipath). 2. The audio in each channel (both desired and undesired) shall be synchronized in time with respect to its respective multipath simulator. 3. For tests E.2 and E.3, analog reference recordings will be made with all relevant permutations of upper/lower adjacent channel interference. 4. The analog reference recordings specified in each step will be made using NRSC analog test receivers #1 and #2 (automobile receivers), and with the IBOC digital sidebands removed from the desired and undesired signals.			
E IBOC ➜ IBOC with multipath	1 Co-channel	1. Test D.1 will be repeated using the four multipath scenarios, except that the desired impairment audio segments will be recorded with the co-channel D/U set at a level 8 dB below (i.e. before) the point of blend (instead of 2 dB).	M	Objective	Co-channel D/U, BLER, mode signal status for each measurement point
				Subjective	Subjective impairment rating for IBOC digital and analog reference recordings made in steps 2, 4
	2 Single and dual 1st adjacent	1. Test D.2 will be repeated using the four multipath scenarios, except that the desired impairment audio segments will be recorded with the 1st adjacent channel D/U set at a level 8 dB below (i.e. before) the point of blend (instead of 2 dB).	M	Objective	1st adj. chan. D/U, BLER, mode signal status for each measurement point
				Subjective	Subjective impairment rating for IBOC digital and analog reference recordings made in steps 2, 4, and 5
	3 Single and dual 2nd adjacent, and simultaneous single 2nd and single 1st adjacent	1. Test D.3 will be repeated using the four multipath scenarios, except that the desired impairment audio segments will be recorded with the 2nd adjacent channel D/U set at a level 8 dB below (i.e. before) the point of blend (instead of 2 dB). If the D/U level at a measurement point is greater than –20 dB, no multipath will be used on the undesired signal for that measurement.	M	Objective	2nd adj. chan. D/U, BLER, mode signal status for each measurement point
				Subjective	Subjective impairment rating for IBOC digital and analog reference recordings made in steps 2, 4, 5, and 6

IBOC LABORATORY TEST PROCEDURES – FM BAND
ANALOG COMPATIBILITY (w/adjacent channel IBOC)

Test Group	Test & Impairment	DESCRIPTION	Desired Signal Level	Type of Evaluation	Test Results Data to be Recorded
		Notes: 1. These tests will compare hybrid IBOC-to-analog with analog-to-analog interference. The desired signal XMTR will be non-IBOC, and the undesired signal XMTR will be hybrid IBOC with the IBOC digital sidebands alternately turned on and off (see below). 2. The test will be conducted with no background RF noise and with RF AWGN equivalent to 30,000K. 3. The undesired analog will be modulated with the interference selection. 4. All NRSC analog test receivers will be used, however, subjective evaluations will only be made for the worst performing interferer (i.e. upper or lower) for each radio UNLESS the performance difference (as determined objectively) between interference cases is > 5 dB.			
F IBOC ➜ Analog (main channel audio) (interference to an analog receiver with no other impairments)	1 Single 1st adjacent	1. The desired signal will be modulated with 1 kHz tone and pilot (no other subcarriers). 2. Using a lower 1st-adjacent channel IBOC interferer, with the IBOC digital sidebands turned on, the desired main channel analog WQP S/N ratio will be measured for D/U settings of 16 dB, 6 dB, -4 dB, -14 dB, and –24 dB. 3. Step 2 will be repeated with the IBOC digital sidebands turned off. 4. Steps 2 and 3 will be repeated using an upper 1st-adjacent channel IBOC interferer.	M (W for -14, -24 dB D/U cases)	Objective	Analog S/N ratio at specified D/Us with IBOC digital sidebands on and off (main channel audio)
	2 Single 2nd adjacent	1. The desired signal will be modulated with 1 kHz tone and pilot (no other subcarriers). 2. Using a lower 2nd-adjacent channel IBOC interferer, with the IBOC digital sidebands turned on, the desired analog WQP S/N ratio will be measured for D/U settings of –20, -25, -30, -35, and -40 dB. 3. Step 2 will be repeated with the IBOC digital sidebands turned off. 4. Steps 2 and 3 will be repeated using an upper 2nd-adjacent channel IBOC interferer.			
	3 Single 1st adjacent	1. The desired signal will be modulated with the desired impairment audio selections (no other subcarriers). 2. Using a lower 1st-adjacent channel IBOC interferer, with the IBOC digital sidebands turned on, audio recordings of the desired signal main channel audio will be made for D/U settings of 16 dB, 6 dB, and –4 dB. 3. Step 2 will be repeated with the IBOC digital sidebands turned off. 4. Steps 2 and 3 will be repeated using an upper 1st-adjacent channel IBOC interferer.	M	Subjective	Subjective impairment rating for each D/U setting for desired main channel analog audio signals with undesired IBOC digital sidebands on and off (for worst performing interferer for each radio only)
	4 Single 2nd adjacent	1. Same as test F.3, using 2nd adjacent instead of 1st adjacent channel interferers, at D/U settings of –20 dB and –40 dB.			

IBOC LABORATORY TEST PROCEDURES – FM BAND
ANALOG COMPATIBILITY (w/adjacent channel IBOC)

Test Group	Test & Impairment	DESCRIPTION	Desired Signal Level	Type of Evaluation	Test Results Data to be Recorded
		Notes: 1. These tests will compare hybrid IBOC-to-analog with analog-to-analog interference for FM subcarriers. The desired signal XMTR will be non-IBOC, and the undesired signal XMTR will be hybrid IBOC with the IBOC digital sidebands alternately turned on and off (see below). 2. The test will be conducted with no background RF noise and with RF AWGN equivalent to 30,000K. 3. The undesired analog will be modulated with the interference selection. 4. All NRSC analog subcarrier test receivers will be used, however, subj. evaluations will only be made for the worst performing interferer (i.e. upper or lower) for each radio UNLESS the performance difference (as determined objectively) between interference cases is > 5 dB.			
F/SC IBOC ➜ Analog (FM subcarriers) (interference to an analog receiver with no other impairments)	1 Single 1st adjacent – analog subcarriers	1. The desired signal will be modulated with CPN, and subcarrier config. #4. 2. Using a lower 1st-adj. chan. IBOC interferer, with the IBOC digital sidebands turned on, the 67 kHz, 92 kHz subcarrier audio WQP S/N ratio will be meas. for D/U settings of 16 dB, 6 dB. 3. Step 2 will be repeated with the IBOC digital sidebands turned off. 4. Steps 2 and 3 will be repeated using an upper 1st-adjacent channel IBOC interferer.	M	Objective	Analog S/N ratio at specified D/Us with IBOC digital sidebands on and off (67 kHz subcarrier audio, 92 kHz subcarrier audio)
	2 Single 2nd adjacent – analog subcarriers	1. The desired signal will be modulated with CPN, and subcarrier configuration #4 (67 kHz and 92 kHz analog). 2. Using a lower 2nd-adjacent channel IBOC interferer, with the IBOC digital sidebands turned on, the 67 kHz and 92 kHz subcarrier audio WQP S/N ratio will be measured for D/U settings of 0, -10 dB, -20 dB, and -30 dB. 3. Step 2 will be repeated with the IBOC digital sidebands turned off. 4. Steps 2 and 3 will be repeated using an upper 2nd-adjacent channel IBOC interferer.			
	3 Single 1st adjacent – digital subcarriers	1. The desired signal will be mod. with CPN, and subcarrier config. #2 (RDS). 2. Using a lower 1st-adjacent channel IBOC interferer, with the IBOC digital sidebands turned on, the subcarrier error rate will be measured for D/U settings of 26 dB, 16 dB and 6 dB. 3. Step 2 will be repeated with the IBOC digital sidebands turned off. 4. Steps 2 and 3 will be repeated using an upper 1st-adjacent channel IBOC interferer. 5. Steps 2-4 will be repeated using subcarrier configuration #3 (HSSC).	M	Objective	Digital subcarrier error rate at specified D/Us with IBOC digital sidebands on and off (RDS, HSSC)

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IBOC LABORATORY TEST PROCEDURES – FM BAND
ANALOG COMPATIBILITY (w/adjacent channel IBOC)

Test Group	Test & Impairment	DESCRIPTION	Desired Signal Level	Type of Evaluation	Test Results Data to be Recorded
		Notes: 1. These tests will compare hybrid IBOC-to-analog with analog-to-analog interference for FM subcarriers. The desired signal XMTR will be non-IBOC, and the undesired signal XMTR will be hybrid IBOC with the IBOC digital sidebands alternately turned on and off (see below). 2. The test will be conducted with no background RF noise and with RF AWGN equivalent to 30,000K. 3. The undesired analog will be modulated with the interference selection. 4. All NRSC analog subcarrier test receivers will be used, however, subj. evaluations will only be made for the worst performing interferer (i.e. upper or lower) for each radio UNLESS the performance difference (as determined objectively) between interference cases is > 5 dB.			
F/SC IBOC ➜ Analog (FM subcarriers) (interference to an analog receiver with no other impairments)	4 Single 2nd adjacent – digital subcarriers	1. The desired signal will be mod. with CPN, and subcarrier config. #2 (RDS). 2. Using a lower 2nd-adjacent channel IBOC interferer, with the IBOC digital sidebands turned on, the subcarrier error rate will be meas. for D/U settings of 0 dB, -10 dB, -20 dB, and -30 dB. 3. Step 2 will be repeated with the IBOC digital sidebands turned off. 4. Steps 2 and 3 will be repeated using an upper 2nd-adjacent channel IBOC interferer. 5. Steps 2-4 will be repeated using subcarrier configuration #3 (HSSC).	M	Objective	Digital subcarrier error rate at specified D/Us with IBOC digital sidebands on and off (RDS, HSSC)
	5 Single 1st adjacent – analog subcarriers	1. The desired signal will be modulated with TBD audio (from audio cut list), and subcarrier configuration #4 (67 kHz and 92 kHz analog). 2. Using a lower 1st-adjacent channel IBOC interferer, with the IBOC digital sidebands turned on, audio recordings of the 67 kHz and 92 kHz subcarrier audio will be made for D/U settings of 16 dB, and 6 dB. 3. Step 2 will be repeated with the IBOC digital sidebands turned off. 4. Steps 2 and 3 will be repeated using an upper 1st-adjacent channel IBOC interferer.	M	Subjective	Subjective impairment rating for each D/U setting for 67 kHz and 92 kHz subcarrier analog audio signals with undesired IBOC digital sidebands on and off (for worst performing interferer for each radio only)
	6 Single 2nd adjacent – analog subcarriers	1. The desired signal will be modulated with TBD audio (from audio cut list), and subcarrier configuration #4 (67 kHz and 92 kHz analog). 2. Using a lower 2nd-adjacent channel IBOC interferer, with the IBOC digital sidebands turned on, audio recordings of the 67 kHz and 92 kHz subcarrier audio will be made for D/U settings of -10 dB and -30 dB. 3. Step 2 will be repeated with the IBOC digital sidebands turned off. 4. Steps 2 and 3 will be repeated using an upper 2nd-adjacent channel IBOC interferer.			

IBOC LABORATORY TEST PROCEDURES – FM BAND ANALOG COMPATIBILITY (w/adjacent channel IBOC)					
Test Group	Test & Impairment	TEST DESCRIPTION Notes: 1. These tests will compare hybrid IBOC-to-analog with analog-to-analog interference. The desired signal transmitter will be non-IBOC, and the undesired signal transmitter will be hybrid IBOC with the IBOC digital sidebands alternately turned on and off (according to the procedures below). 2. Both desired and undesired signals will be subject to multipath fading, using the urban slow and urban fast multipath scenarios. 3. The test will be conducted with no background RF noise and with RF AWGN equivalent to 30,000K. 4. The undesired channel will be modulated with the multipath interference selection. 5. The audio in each channel (both desired and undesired) shall be synchronized in time with respect to its respective multipath simulator. 6. NRSC analog test receivers #1 and #2 (automobile receivers) will be used for this test, however, subjective evaluations will only be made for the worst performing interferer (i.e. upper or lower) for each radio UNLESS the performance difference (as determined objectively) between interference cases is > 5 dB.	Desired Signal Level	Type of Evaluation	Test Results & Data to be Recorded
G IBOC ➜ Analog (main channel audio) with multipath (interference to an analog receiver with multipath on the desired and undesired signals)	1 Single 1st Adjacent	1. The desired signal will be modulated with the desired impairment audio selections. 2. Using a lower 1st-adjacent channel IBOC interferer, with the IBOC digital sidebands turned on, audio recordings of the desired signal will be made for the urban slow and urban fast multipath scenarios, for a D/U setting of +6 dB. 3. Step 2 will be repeated with the IBOC digital sidebands turned off. 4. Steps 2 and 3 will be repeated using an upper 1st-adjacent channel IBOC interferer.	M	Subjective	Subjective impairment rating for desired analog signal with undesired IBOC digital sidebands on and off (for worst performing interferer for each radio only)

IBOC LABORATORY TEST PROCEDURES – FM BAND
DIGITAL PERFORMANCE

Test Group	Test & Impairment	TEST DESCRIPTION Notes: 1. The audio will be the classical music selection of the desired impairment audio. 2. Each acquisition recording will last one minute. 3. Each test will be repeated at least five times and the results recorded for further assessment.	Desired Signal Level	Type of Evaluation	Test Results Data to be Recorded
H IBOC acquisition	1 Acquisition with varying signal level	1. Using the strong signal level, the RF input will be disconnected from the receiver (as close to the receiver input connector as possible) for sixty seconds to assure loss of lock. 2. The signal will then be reconnected to the IBOC receiver. 3. The audio start will be synchronized with the signal reconnection. 4. The time to audio output will be measured in seconds using a digital oscilloscope (in storage mode). 5. Steps 1-4 will be repeated with the moderate signal level. 6. Steps 1-5 will be repeated with a +6 dB D/U lower first adjacent interferer.	S & M	Objective	Acquisition time at each noise level and audio recordings based upon laboratory observation (listening)

IBOC LABORATORY TEST PROCEDURES – FM BAND DIGITAL QUALITY					
Test Group	Test & Impairment	TEST DESCRIPTION	Desired Signal Level	Type of Evaluation	Test Results & Data to be Recorded
I IBOC quality	1 Quality transmission test	1. Tests will be conducted using the audio quality selections. 2. Each of the selections will be transmitted through the IBOC system without impairment and recorded for subjective evaluation. 3. For each measurement point, the mode signal status will be recorded.	S	Objective	Mode signal status of system during recording of audio selections
				Subjective	Subjective rating for each audio quality selection

IBOC LABORATORY TEST PROCEDURES – FM BAND
ANALOG COMPATIBILITY (Host)

Test Group	Test & Impairment	TEST PROCEDURE Note: 1. The test will be conducted with no background RF noise and with RF AWGN equivalent to 30,000K.	Desired Signal Level	Type of Evaluation	Test Results Data to be Recorded
J IBOC ➜ Host analog	1 IBOC to host analog	1. All 4 NRSC analog test receivers will be used for this test. 2. The host FM transmitter will be set for a total of 75 kHz deviation, modulated with a 1 kHz tone and pilot. 3. With the host IBOC digital sidebands turned on, the host analog WQP S/N ratio, and stereo separation will be measured. 4. Step 3 will be repeated with the host IBOC digital sidebands turned off.	S	Objective	Host analog S/N ratio, stereo separation, with IBOC digital sidebands on and off
	2 IBOC to host analog	1. All 4 NRSC analog test receivers will be used for this test. 2. The host FM transmitter will be set for a total of 75 kHz deviation, modulated with the desired impairment audio selections. 3. With the host IBOC digital sidebands turned on, audio recordings of the host analog the desired signal will be made. 4. Step 3 will be repeated with the host IBOC digital sidebands turned off.	S	Subjective	Subjective impairment rating of host analog audio with IBOC digital sidebands on and off
	3 IBOC to subcarriers – baseband spectral plots	1. The host FM transmitter will be set for a total of 75 kHz deviation, modulated with a 1 kHz tone and pilot. 2. With the host IBOC digital sidebands turned on , the received baseband noise floor (100 Hz to 300 kHz) will be plotted using a wideband precision demodulator. 3. Step 2 will be repeated with the host IBOC digital sidebands turned off. 4. Steps 2 and 3 will be repeated with the 1 kHz program audio tone removed.	S & M	Objective	Baseband noise floor plots for various operating conditions
	4 IBOC to subcarriers – analog subcarrier performance	1. The FM host channel will be modulated with pilot, CPN on main channel audio, and subcarrier configuration #1 (RDS, 67 kHz analog, 92 kHz analog). 2. With the host IBOC digital sidebands turned on, the analog subcarrier S/N ratio will be measured on both 67 kHz and 92 kHz subcarriers. 3. Step 2 will be repeated with the host IBOC digital sidebands turned off. 4. With the host IBOC digital sidebands turned on, and the FM host channel main channel audio modulation changed from CPN to TBD (from audio cut list), audio recordings will be made of both the 67 kHz and 92 kHz subcarriers using TBD audio. 5. Step 4 will be repeated with the host IBOC digital sidebands turned off.	S & M	Objective	Analog subcarrier audio S/N ratio with IBOC digital sidebands on and off
				Subjective	Subjective rating for each audio quality selection

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IBOC LABORATORY TEST PROCEDURES – FM BAND
ANALOG COMPATIBILITY (Host)

Test Group	Test & Impairment	TEST PROCEDURE Note: 1. These tests will be conducted with no background RF noise and with RF AWGN equivalent to 30,000K.	Desired Signal Level	Type of Evaluation	Test Results Data to be Recorded
J IBOC ➜ Host analog	5 IBOC to subcarriers – RDS subcarrier performance	1. The FM host channel will be modulated with pilot, CPN on main channel audio, and subcarrier configuration #1 (RDS at 3% injection). 2. With the host IBOC digital sidebands turned on, the RDS BLER will be measured. [RDS MEASUREMENT SOFTWARE TBD] 3. Step 2 will be repeated with the host IBOC digital sidebands turned off. 4. Steps 2 and 3 will be repeated with the 1 kHz program audio tone removed. 5. Steps 2-4 will be repeated, substituting subcarrier configuration #1 with subcarrier configuration #2 (RDS at 10% injection).	S & M	Objective	RDS error rate for various operating conditions
	6 IBOC to subcarriers – “high speed” digital subcarrier (HSSC) performance	1. The FM host channel will be modulated with pilot, CPN on main channel audio, and subcarrier configuration #3 (HSSC). 2. With the host IBOC digital sidebands turned on, the high speed digital subcarrier (HSSC) BLER will be measured. 3. Step 2 will be repeated with the host IBOC digital sidebands turned off. 4. Steps 2 and 3 will be repeated with the 1 kHz program audio tone removed.	S & M	Objective	HSSC error rate for various operating conditions

NRSC Analog Test Receivers			
Number	Make and Model	Type	Age in Years
1	Delphi Model: 09394139	Auto OEM	New
2	Pioneer Model: KEH-1900	Auto Aftermarket	New
3	Technics Model: SA-EX140	Home HiFi	New
4	Sony Model: CFD-S32	Table Combo	New

NRSC Analog Subcarrier Test Receivers			
Number	Make and Model	Type	Age in Years
5	McMartin	67 kHz	
6	Norver	67 kHz Reading services	
7	CozmoCom	92 kHz	
8	ComPol SCA-BL	92 kHz	

Appendix C –
IBOC field test procedures – FM band

NATIONAL
RADIO
SYSTEMS
COMMITTEE

DAB Subcommittee
Evaluation of the iBiquity Digital Corporation IBOC System

Part 1 – FM IBOC

IBOC FIELD TEST PROCEDURES – FM BAND
OVERALL COMMENTS

1. The independent engineering consultant (TBD) will provide a detailed certification of the mobile test vehicle including the stationary test platforms.
2. Appendix A is a table and set of maps which describe the test stations and test routes which this procedure is to be conducted for. Note that the test routes depicted therein represent the best possible estimate of the routes to be used, and that accommodations may be made during the actual test run due to road construction, etc. Maps of the actual routes taken will be provided in the field test record.
3. IBOC receiver point-of-blend is established by the “mode” signal which is supplied by the receiver. IBOC receiver block error rate (BLER) is also observable.
4. Unless otherwise specified, the audio selections to be used as source material for desired and interfering channels will be “audio of opportunity,” and, the source audio for analog reference recordings will be the same as that used for the corresponding IBOC digital audio recordings.
5. Digital recordings of analog and IBOC digital audio indicated by these procedures are for archival and/or subjective evaluation purposes. All such recordings will be made in the following format: uncompressed linear 16-bit digital audio sampled at 44.1 kHz, and will be suitable for transfer to CD to facilitate further analysis.
6. The detailed procedure for RF noise measurements will be supplied.
7. The host FM to digital power ratio used in the digital performance tests will also be used for the analog compatibility tests.
8. Appendix A contains information on the stations and test routes to be used for these tests.
9. NRSC analog test receivers specified on pg. 5 will undergo the following characterization tests: [list TBD]
10. Test record will indicate direction of travel on all routes
11. All radial routes (this includes all field test locations except San Francisco) will be driven to the IBOC point of failure (POF), that is, until the IBOC signal is fully blended to analog.
12. “Strip chart” data plots will be included in the test record for all test routes [*e.g.*, a plot from USADR phase 1 submission will be included here].
13. NRSC will participate in selection of specific field test audio cuts to be submitted for subjective evaluation in a TBD fashion.

IBOC FIELD TEST PROCEDURES – FM BAND
CALIBRATION

Test Group	Test & Impairment	TEST DESCRIPTION Notes: 1. This calibration will be performed for each test station.	Type of Evaluation	Test Results Data to be Recorded
A Calibration	1 Power (as needed)	1. Analog power will be read by station's existing test equipment. 2. Digital power will be determined using a spectrum analyzer.	Objective	Analog average power level Digital average and peak power levels
	2 Spectrum (daily)	1. Spectrum analyzer plots of the system RF will be taken at the output of the transmission system. 2. The spectrum analyzer settings will be: (a) RES BW 1.0 kHz, VBW 30 Hz and sweep span 2.0 MHz, and (b) RES BW 1.0 kHz, VBW 30 Hz and sweep span 0.5 MHz (transmission line test). All plots will be made using digital averaging of at least 100 sweeps. 3. Four plots of the spectrum will be made: two at setting (a) with and without IBOC digital sidebands, and two at setting (b) with and without IBOC digital sidebands. 4. Test station modulation monitor readings will be recorded.	Objective	Daily power ratios and out-of-channel radiation monitored at combiner output
	3 Monitor (beginning of test period)	1. Test station occupied bandwidth characteristics will be established by the test crew using a spectrum analyzer in both "average" and "peak hold" modes.	Objective	Certification should be recorded in field test record
	4 Receiver antenna performance and data	1. A detailed description of the receiving antenna and RF distribution system will be included in the field test report. 2. If any active RF device is used, a full set of RF performance test results will be supplied with the report.	Objective	
	5 General	1. All test equipment will be certified to be in compliance with manufacturer's specifications and calibration schedules.	Objective	Calibration results

IBOC FIELD TEST PROCEDURES – FM BAND DIGITAL PERFORMANCE				
Test Group	Test & Impairment	TEST DESCRIPTION Notes: 1. Radials will be selected to demonstrate system performance under the following conditions: a) low interference and low multipath b) low interference and moderate/strong multipath c) single first adjacent interferer d) single second adjacent interferer e) simultaneous dual interferers, to the extent feasible f) terrain obstructions g) centrally-located urban antenna h) combined antenna i) strong single 1st adjacent interferer j) low power combiner/common amplification (otherwise high-power combiner assumed) k) class A FM facility l) 67 kHz analog subcarrier compatibility m) 92 kHz analog subcarrier compatibility n) RDS subcarrier compatibility o) DARC subcarrier compatibility 2. Radials will start within 1.0 mile of the transmitter (where possible) and extend beyond the edge of digital coverage. 3. Audio recordings in a digital format of both the analog and digital received audio will be made. 4. Recordings of the test route will be made including GPS data, derived signal strength and adjacent channel signal strength. 5. For all tests, stations will broadcast their regular programming. 6. NRSC analog test receiver #1 will be used for analog reception.	Type of Evaluation	Test Results Data to be Recorded
B System performance	1 Low interference and low multipath	1. The undesired first adjacent analog signal should be at least 10 dB below the digital signal. 2. The undesired analog second adjacent D/U should not exceed a D/U of -20 dB in the test area.	Objective	Mode signal, various RF signal levels [see example plot]
			Subjective	Analog recordings (to be subjectively evaluated)
	2 1st-adjacent interference	1. First adjacent interferer will be in an area where the interfering signal exceeds 6 dB below the desired signal.	Objective	Mode signal, various RF signal levels [see example plot]
			Subjective	Analog recordings (to be subjectively evaluated)
	3 2nd-adjacent interference	1. Second adjacent interferer will be at least 20 dB above the desired signal.	Objective	Mode signal, various RF signal levels [see example plot]
			Subjective	Analog recordings (to be subjectively evaluated)

IBOC FIELD TEST PROCEDURES – FM BAND
ANALOG COMPATIBILITY

Test Group	Test & Impairment	TEST DESCRIPTION	Type of Evaluation	Test Results Data to be Recorded
		Notes: 1. Tests C.1 and C.2 are host compatibility tests i.e. the analog receivers under test will be tuned to the host IBOC station. 2. Test C.3 is a non-host compatibility test i.e. the analog receiver under test will be tuned to a normal analog station which is 1st-adjacent to an IBOC station (as specified in note 5). 3. Host compatibility (main channel audio) tests (C.1) will be conducted at stations WETA and WPOC. 4. Host compatibility (analog and digital subcarriers) tests (C.2) will be conducted at stations TBD. 5. 1st-adjacent compatibility tests (C.3) will be conducted at WPOC and WNEW.		
C Compatibility	1 Host compatibility – main channel audio	1. Fixed compatibility tests will be conducted using all NRSC Test Receivers. 2. The digital signal should be switched on for 30 seconds and off for 30 seconds. This should be repeated twice. 3. Recordings will be made at 3 locations with strong desired signals, and as free as possible of other (undesired) strong signals, so as to maximize potential for host interference.	Objective	Mode signal, various RF signal levels [see example plot]
			Subjective	Analog recordings (to be subjectively evaluated)
	2 Host compatibility – analog and digital subcarrier s	1. Fixed compatibility tests will be conducted using commercially available subcarrier receivers. 2. The digital signal should be switched on for 30 seconds and off for 30 seconds. This should be repeated twice. 3. Recordings will be made at 3 locations with strong desired signals, and as free as possible of other (undesired) strong signals, so as to maximize potential for host interference. 4. Tests of analog subcarriers will be conducted with 57, 67 and 92 kHz subcarriers with total injection of less than 20%. 5. Test of digital subcarrier will be conducted at 57 kHz and using a subcarrier at 76 kHz with a total injection of 10%. 6. BLER shall be recorded with DAB on and off for all relevant subcarriers.	Objective	Mode signal, various RF signal levels [see example plot]
			Subjective	Analog recordings (to be subjectively evaluated)
	3 1st-adjacent compatibility	1. Fixed compatibility tests will be conducted using all test receivers. 2. Test will be conducted at a point where the first adjacent signal is on the order of 6 dB less than the desired analog signal. 3. Recordings will be made at 3 locations.	Objective	Mode signal, various RF signal levels [see example plot]
			Subjective	Analog recordings (to be subjectively evaluated)

NRSC Analog Test Receivers			
Number	Make and Model	Type	Age in Years
1	Delphi Model: 09394139	Auto OEM	New
2	Pioneer Model: KEH-1900	Auto Aftermarket	New
3	Technics Model: SA-EX140	Home HiFi	New
4	Sony Model: CFD-S32	Table Combo	New

NRSC Analog Subcarrier Test Receivers			
Number	Make and Model	Type	Age in Years
5	McMartin	67 kHz	
6	Norver	67 kHz Reading services	
7	CozmoCom	92 kHz	
8	ComPol SCA-BL	92 kHz	

APPENDIX A

NRSC IBOC DAB Evaluation - FM Field Test Stations

Table 1 – Test Condition Matrix (see notes on page 2)

No	Call Sign	Freq. (MHz)	Format	Location	Test Condition(s) a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	Comments
1	WETA	90.9	Talk and classical	Washington, D.C.	✔															• Coverage (8-radial test) • Host compatibility (no interferers – best station for host compatibility tests)
2	WPOC	93.1	Country	Baltimore, MD			✔													• Host compatibility • 2nd adjacent interferer to 93.5 MHz (WD2XAB) – used as 2nd adjacent undesired for compatibility testing with WD2XAB • 1st-adj. compatibility (0º radial) • 1st adj. compatibility and performance (180º radial) • 2nd-adj. performance (undesired)
3	WD2XAB	93.5	Test	Columbia, MD				✔												• Used as 2nd adjacent desired for compatibility testing with WPOC • 2nd-adj. performance (desired)
4	KLLC	97.3	“Alice”	San Francisco, CA		✔				✔										• Terrain obstructions • EIA/NRSC test routes used (from 1996 tests) – closed path, not radials
5	WHFS	99.1	Rock	Annapolis, MD					✔											2nd-adj. compatibility (270º radial)
6	KWNR	95.5	Country	Las Vegas, NV		✔				✔										• “Specular” multipath • Terrain obstructions
7	WNEW	102.7	Talk and rock (weekends)	New York, NY		✔					✔	✔	✔							• 1st-adj. compatibility • “Specular" multipath
8	WWIN	95.9	Urban (pop)	Baltimore, MD				✔						✔	✔					
				Number of stations with given test condition ➔	1	3	1	2	1	2	1	1	1	1	1					Subcarrier conditions (l-o) TBD
1R	WGRV	105.1	Urban oldies	Detroit, MI				✔												• Reserve – will only be used if problems prevent use of one or more of stations 1-8 • 2nd-adj. performance (180º radial)

<u>Notes for Table 1</u>:

1. Proponent will run at least 4 radials for each test station
2. Proponent will supply maps of the test radials plotted against predicted analog coverage and strip charts for each station
3. Select radials noted above will be extracted for further analysis and subjective evaluation
4. Multipath examples for subjective evaluation will be selected from recordings of multiple stations
5. Test conditions (see Field Test Procedure, Test B Notes):
    (a) low interference and low multipath
    (b) low interference and moderate/strong multipath
    (c) single first adjacent interferer
    (d) single second adjacent interferer
    (e) simultaneous dual interferers, to the extent feasible
    (f) terrain obstructions
    (g) centrally-located urban antenna
    (h) combined antenna
    (i) strong single 1st adjacent interferer
    (j) low power combiner/common amplification (otherwise high-power combiner assumed)
    (k) class A FM facility
    (l) 67 kHz analog subcarrier compatibility
    (m) 92 kHz analog subcarrier compatibility
    (n) RDS subcarrier compatibility
    (o) DARC subcarrier compatibility

Table 2. Station List for IBOC to Analog Compatibility Testing

Compatibility Type	Station of Interest Format Location	Freq. (MHz) Channel	Interfering Station Format Location	Freq. (MHz) Channel	Interferer location	Station Spacing
Host	WETA (IBOC) Classical/Talk Washington DC	90.9 215B				
Host	WPOC (IBOC) Country Baltimore, MD	93.1 226B				
First Adjacent	WMMR (FM) Rock Philadelphia, PA	93.3 227B	WPOC (IBOC) Country Baltimore, MD	93.1 226B	Upper	155 km
First Adjacent	WFLS (FM) Country Fredericksburg, VA	93.3 227B	WPOC (IBOC) Country Baltimore, MD	93.1 226B	Upper	123 km
First Adjacent	WMGK (FM) Classic Rock Philadelphia, PA	102.9 275B	WNEW (IBOC) Talk/Rock New York, NY	102.7 274B	Lower	132 km
Second Adjacent	WMZQ (FM) Country Washington DC	98.7 254B	WHFS (IBOC) Rock Annapolis, MD	99.1 256B	Upper	43 km
Second Adjacent	WJMO (FM) Jammin'Oldies Washington DC	99.5 258B	WHFS (IBOC) Rock Annapolis, MD	99.1 256B	Lower	39 km

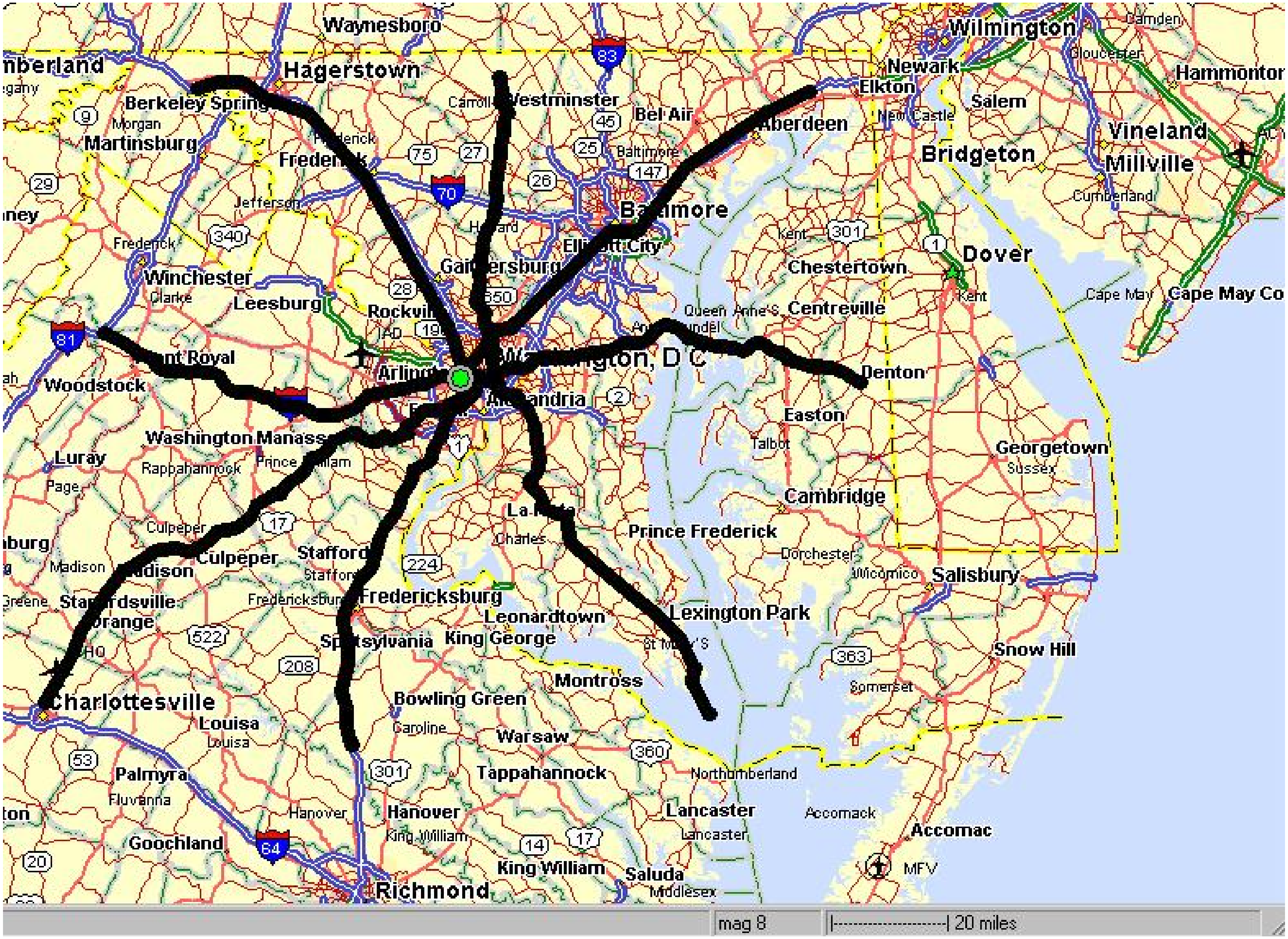
Table 3a. Station List for IBOC Performance Testing – Part 1 of 2

Test Station Format Location	Freq. (MHz) Channel	Subcarriers (TBD)	Propagation & Testing Features	Significant Interferers	Drive Routes
WETA Classical/Talk Washington DC	90.9 215B		Terrain Obstructed M/P; Urban performance of suburban TX site	Analog Co-channel WHYY in Philadelphia, Class B @ 207 km	Eight radials
WPOC Country Baltimore, MD	93.1 226B		Urban/suburban performance of suburban TX site	Analog 1st Adjacent WFLS in Fredericksburg, VA, 93.3 MHz, Class B @ 124 km	Five radials plus fork in southern radial toward WFLS
KLLC “Alice” San Francisco, CA	97.3 247B		Severe, Terrain Obstructed M/P		EIA loops as established in 1995 testing
WHFS Rock Annapolis, MD	99.1 256B			Analog 2nd Adjacents WMZQ in Wash. DC, 98.7 MHz, Class B @ 43 km WJMO in Wash. DC, 99.5 MHz, Class B @ 39 km	1 path from station toward area of 2nd adjacent stations
KWNR Country Henderson, NV	95.5 238C		Specula M/P, Class C station		Eight radials, including Las Vegas “Strip”

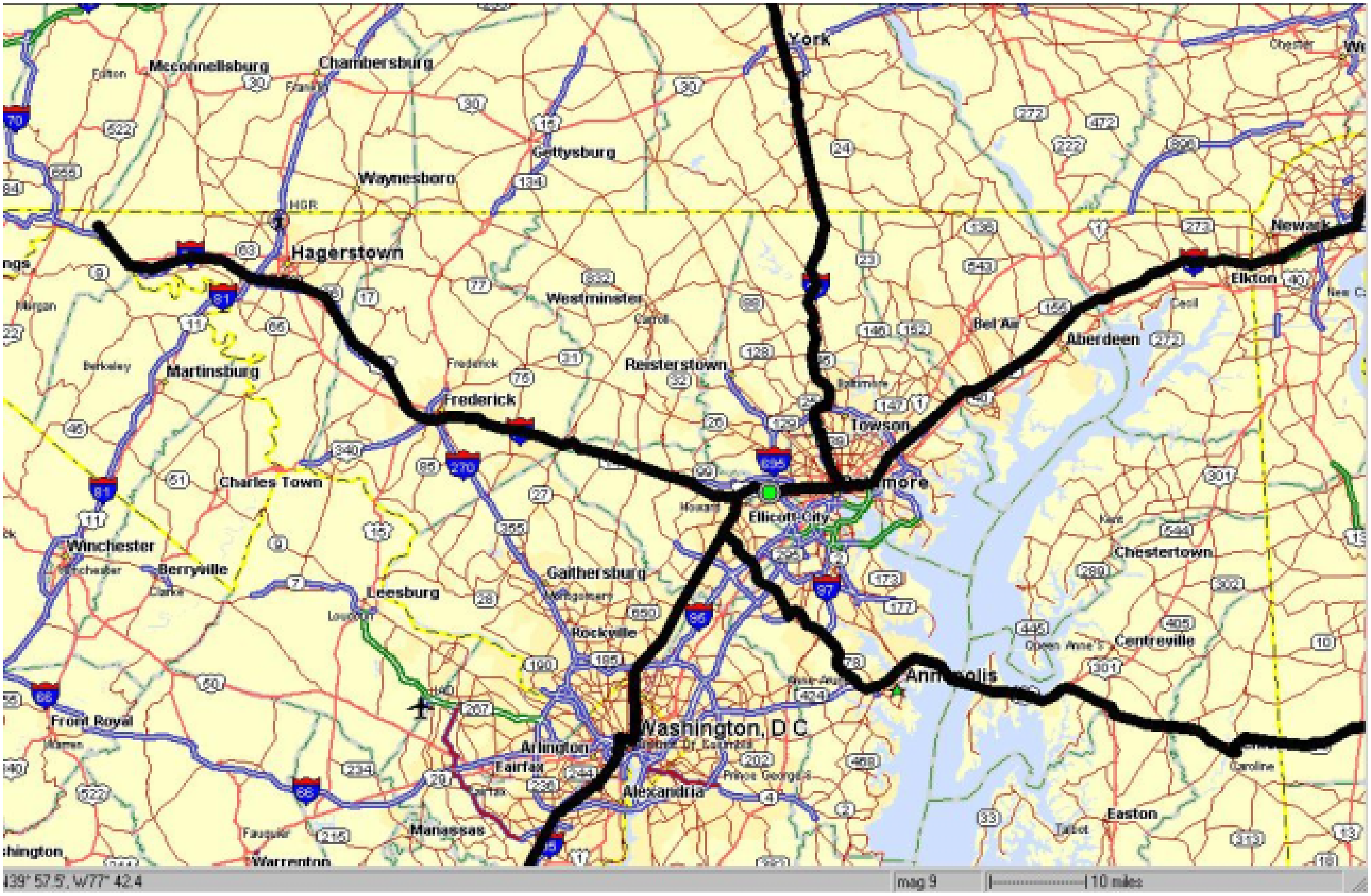
Table 3b. Station List for IBOC Performance Testing – Part 2 of 2

Test Station Format Location	Freq. (MHz) Channel	Subcarriers (TBD)	Propagation and Testing Features	Significant Interferers	Drive Routes
WNEW Talk/Rock New York, NY	102.7 274B		Urban and Terrain Obstructed M/P; Test of Urban and suburban coverage from central, urban TX site on master antenna system		Urban circles combined with four radials
WWIN Urban Pop Glen Burnie, MD	95.9 240A		Class A station with low power combining and common analog/IBOC amplification	Analog 2nd Adjacent WHUR in Wash. DC, 96.3 MHz, Class B @ 52 km	Four radials
WD2XAB, experimental Varied, as required Columbia, MD	93.5 228A		Suburban Class A station	IBOC 2nd Adjacent WPOC in Baltimore, 93.1 MHz Class B @ 12 km Analog 2nd Adjacent WKYS in Wash. DC, 93.9 MHz Class B @ 36 km	Four radials
WGRV Urban Oldies Farmington Hill, MI	105.1 286B		Reserve Test Station	TBD if required	TBD if required

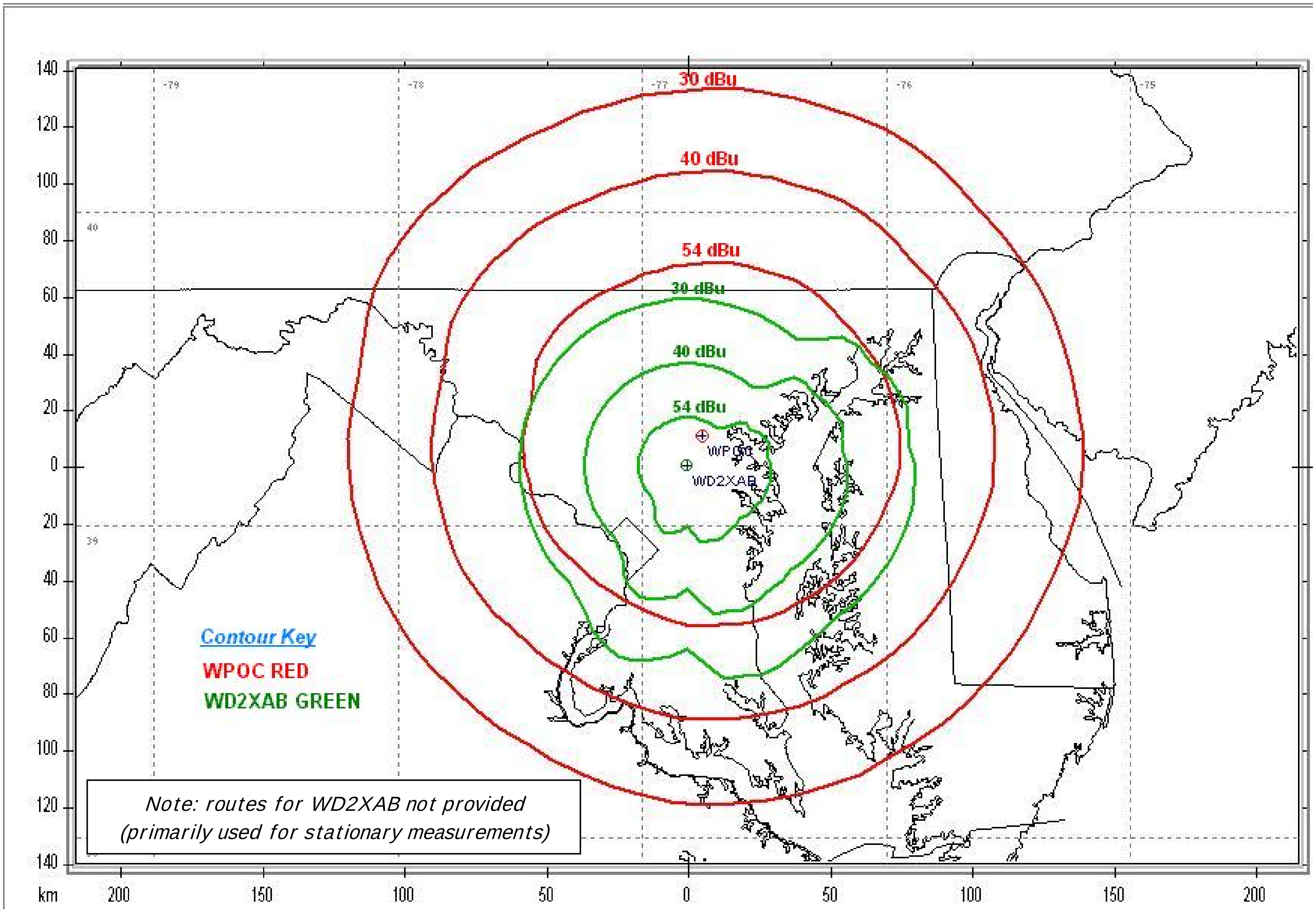
Field test route map – WETA-FM (wetamapR2.jpg)



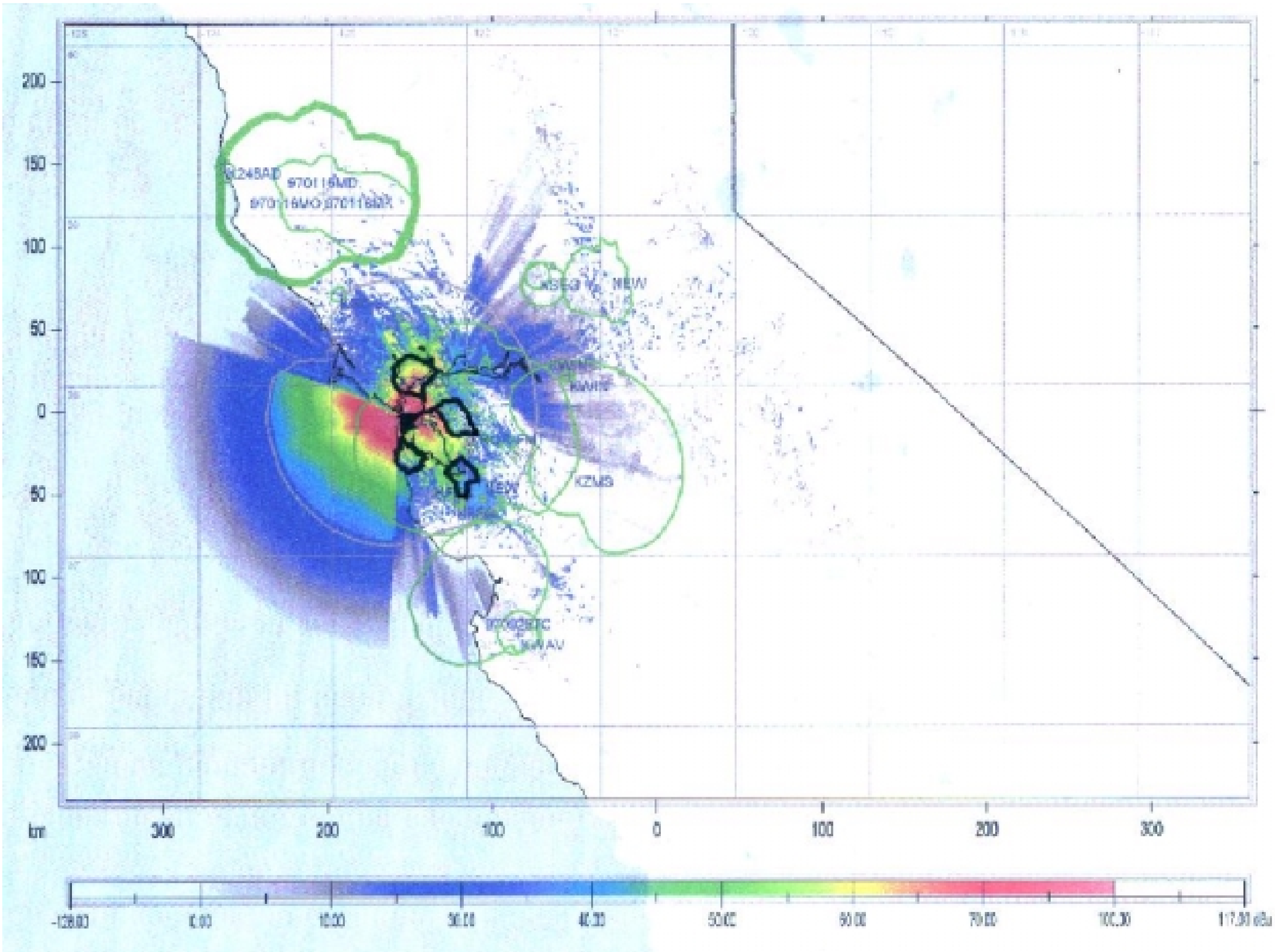
Field test route map – WPOC-FM (wpocmapR2.jpg)



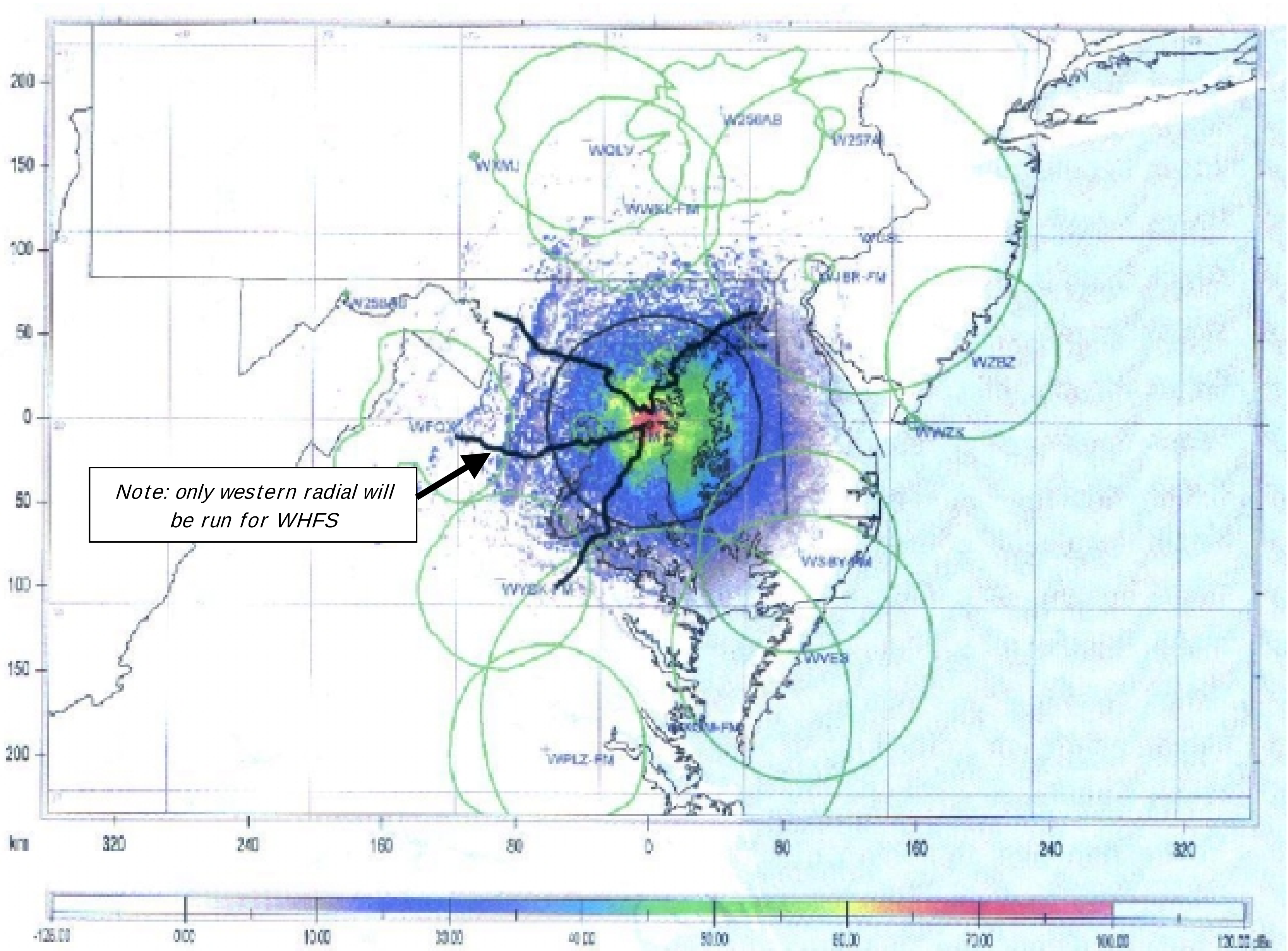
Field test route map – WD2XAB-FM (WPOC-WD2XAB contours.jpg)



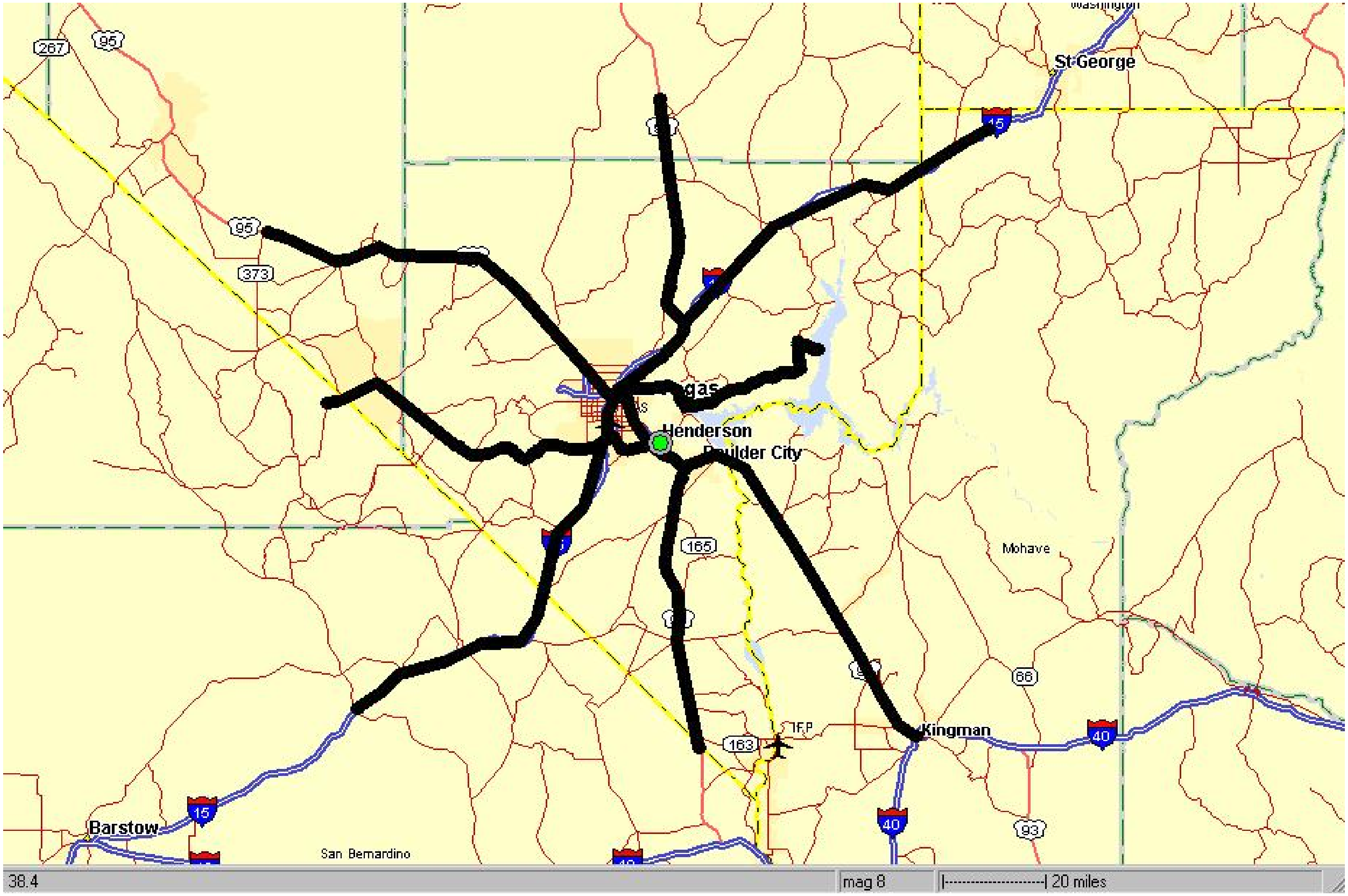
Field test route map – KLLC-FM (kllc.jpg)



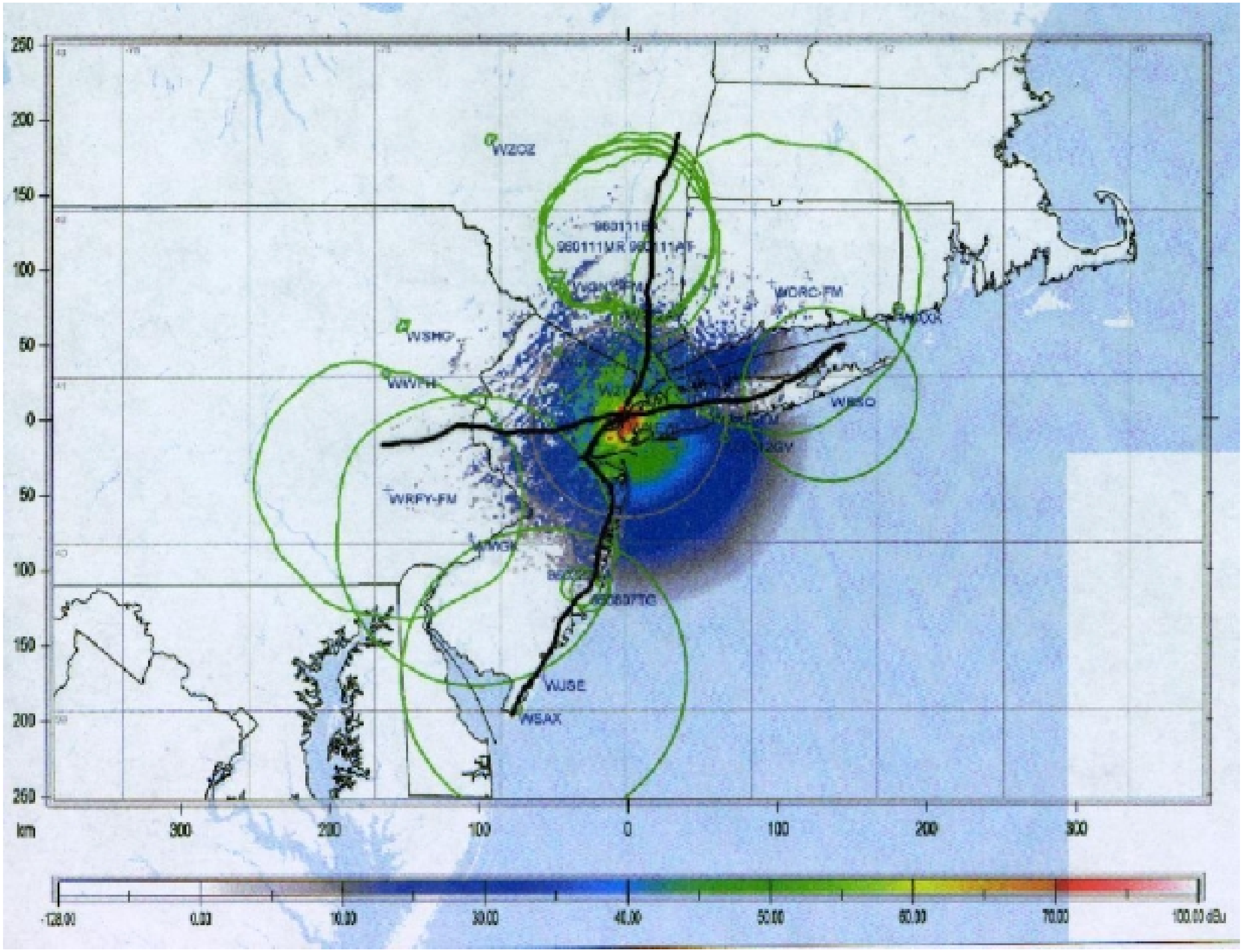
Field test route map – WHFS-FM (whfs1.jpg)



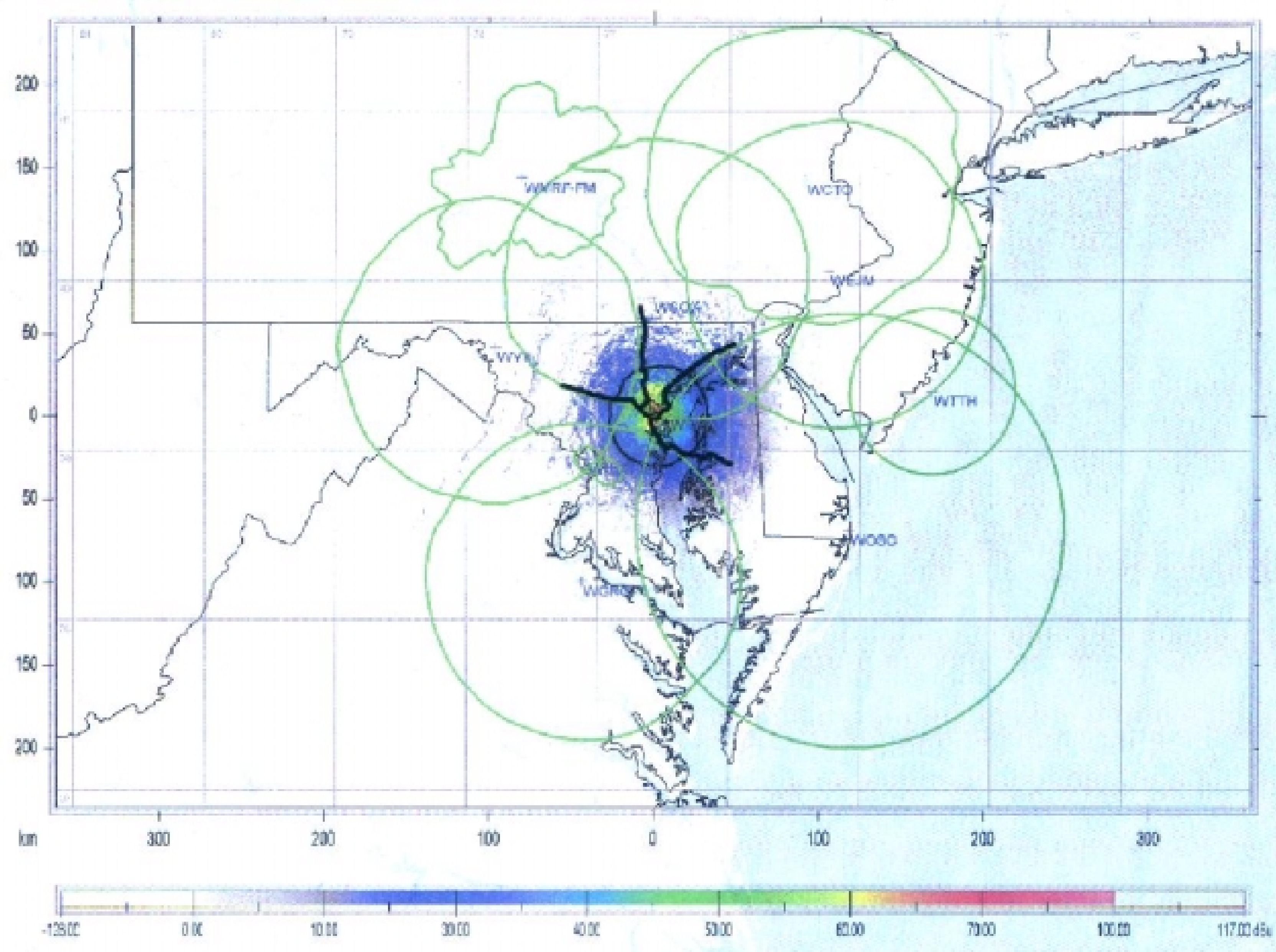
Field test route map – KWNR-FM (kwnrmapR2.jpg)



Field test route map – WNEW-FM (wnew.jpg)



Field test route map – WWIN-FM (wwin.jpg)



Appendix D –
NRSC analog receiver characterization

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Evaluation of the iBiquity Digital Corporation IBOC System

Part 1 – FM IBOC

The NRSC's FM IBOC compatibility and analog reference tests used four consumer FM stereo receiver models. These receivers were selected because their RF performance characteristics represent receivers used for FM stereo broadcast reception in the U.S. The table lists the receiver make, type, and IBOC test facility. The same model of each manufacture's receiver was used.

FM Receivers Used in the IBOC Laboratory and Field Tests				
Reference number	**Make**	**Type**	**Test**	**Characterization test size**
01	Delphi	Auto	Field west	Full
02	Delphi	Auto	ATTC laboratory	Full
03	Delphi	Auto	Field east	Short Form
05	Technics	Hi-fi	ATTC laboratory	Full
06	Technics	Hi-fi	Field compatibility	Full
10	Sony	Portable/Table	ATTC laboratory	Full
11	Sony	Portable/Table	Field compatibility	Short Form
17	Pioneer	Auto	Field west	Full
18	Pioneer	Auto	ATTC laboratory	Full
19	Pioneer	Auto	Field East	Short Form

Prior to the start of IBOC laboratory and field-testing an independent test laboratory characterized each receiver for RF sensitivity, RF selectivity, stereo separation, image rejection, IM, and sensitivity to narrow band noise. Over eighteen receivers were characterized of which the ten listed in the above table were used for the IBOC compatibility tests and digital performance tests.

The independent test laboratory conducted seventeen-characterization tests on seven of the ten receivers. Because of time restraints a limited number of characterization tests were conducted on the three remaining receivers. The short form receiver characterization tests consisted of distortion, RF level/SN, stereo separation, 1st adjacent selectivity, 2nd adjacent selectivity, IM, and narrowband noise sensitivity.

The following is a list of the characterization tests - those tests included in short form testing are noted (SF):

1) Local oscillator frequency
2) (SF) Distortion at standard output level
3) RF input overload
4) AM rejection
5) Image rejection
6) (SF) Curve tests – plots of RF level vs. signal-to-noise (mono, stereo); RF level vs. stereo separation
7) Capture ratio
8) Selectivity – 1st adjacent (for 30dB RMS S/N)
9) Selectivity – 2nd adjacent (for 30dB RMS S/N)
10) (SF) Selectivity – 1st adjacent (for 50dB RMS S/N)
11) (SF) Selectivity – 2nd adjacent (for 50dB RMS S/N)
12) Selectivity – 3rd adjacent (for 50dB RMS S/N)
13) 10.7 MHz rejection (not done)
14) 10.7 MHz intermodulation
15) Local oscillator interference
16) (SF) Intermodulation
17) (SF) Narrowband noise sensitivity

Included below are summary tables of the receiver characterization data collected for all ten receivers used for the NRSC lab and field IBOC compatibility and performance tests. The tables list the receiver make, test results, and the test facility (lab or field). The tables allow for the direct comparison of receiver basic performance parameters. Each table does not show all the parameters tested. Complete listings of all the test data are in the detailed receiver test reports.[1]

Attachment 1 to this Appendix includes block diagrams of each test mode; in Attachment 2, an example of a full receiver characterization report is given, for one of the Delphi receivers tested.

1) Local oscillator frequency

94.1 + 10.7 = 104.8 MHz

Receiver	LO Frequency MHz	Deviation MHz	Test
01 Delphi	104.801	+0.001	Field west
02 Delphi	104.801	+0.001	ATTC laboratory
03 Delphi	Short Form	-	Field east
05 Technics	104.750	-0.050	ATTC laboratory
06 Technics	104.748	-0.052	Field compatibility
10 Sony	104.801	+0.001	ATTC laboratory
11 Sony	Short Form	-	Field compatibility
17 Pioneer	104.799	-0.001	Field west
18 Pioneer	104.798	-0.002	ATTC laboratory
19 Pioneer	Short Form	-	Field East

[1] To be published by the NRSC.

2) (SF) Distortion at standard output level

1 kHz tone 75 kHz deviation, mono; test setup 2

Receiver	THD % Left	THD % Right	Test
01 Delphi	0.43	0.43	Field west
02 Delphi	0.48	0.35	ATTC laboratory
03 Delphi	0.40	0.40	Field east
05 Technics	0.15	0.18	ATTC laboratory
06 Technics	0.17	0.17	Field compatibility
10 Sony	0.28	0.28	ATTC laboratory
11 Sony	0.32	0.27	Field compatibility
17 Pioneer	0.38	0.39	Field west
18 Pioneer	0.36	0.38	ATTC laboratory
19 Pioneer	0.32	0.33	Field East

3) RF input overload

1 kHz tone, 75 kHz dev, mono; increase RF level until 5% THD at radio output, and record RF level; test setup 1

Receiver	RF level in dBm at 5% THD	Test
01 Delphi	22	Field west
02 Delphi	22	ATTC laboratory
03 Delphi	SF	Field east
05 Technics	22	ATTC laboratory
06 Technics	22	Field compatibility
10 Sony	20.2	ATTC laboratory
11 Sony	SF	Field compatibility
17 Pioneer	22	Field west
18 Pioneer	22	ATTC laboratory
19 Pioneer	SF	Field east

4) AM rejection

1 kHz tone 75 kHz deviation, mono; set radio audio to std. ref. level and record THD; set modulation mode to FM (75 kHz), AM (30%), record THD; test setup 2

Receiver	THD difference in dB	Test
01 Delphi	-0.10	Field west
02 Delphi	0.00	ATTC laboratory
03 Delphi	SF	Field east
05 Technics	-0.83	ATTC laboratory
06 Technics	-3.00	Field compatibility
10 Sony	0.00	ATTC laboratory
11 Sony	SF	Field compatibility
17 Pioneer	0.00	Field west
18 Pioneer	0.00	ATTC laboratory
19 Pioneer	SF	Field east

5) Image rejection

Set radio audio to std. ref. level; decrease RF level until S/N ratio = 30dB, record RF level 1; tune RF gen to desired freq. +/- 2X freq.; adjust RF level until S/N ratio= 30dB, record RF level 2; test setup 2

Receiver	Image Rejection in dB	Test
01 Delphi	-48	Field west
02 Delphi	-49	ATTC laboratory
03 Delphi	SF	Field east
05 Technics	-53	ATTC laboratory
06 Technics	-52	Field compatibility
10 Sony	-22	ATTC laboratory
11 Sony	SF	Field compatibility
17 Pioneer	-44	Field west
18 Pioneer	-44	ATTC laboratory
19 Pioneer	SF	Field east

6) (SF) RF level vs. S/N, separation

S/N WQP; signal, noise vs. RF level mono; signal, noise vs. RF level stereo; stereo separation vs. RF level; test setup 2

Receiver	Mono WQP S/N at –55dBm / -90dBm	Stereo WQP S/N at –55 dBm / –90 dBm	Separation at –55 dBm / –90 dBm
01 Delphi	64/45	56/45	29/0
02 Delphi	64/45	56/45	29/.5
03 Delphi	63/46	55/46	31/0
05 Technics	64/49	58/29	36/26
06 Technics	64/50	58/28	28/23
10 Sony	55/43	51/23	40/22
11 Sony	56/45	51/24	39/24
17 Pioneer	58/44	53/44	33/0
18 Pioneer	59/46	54/46	34/0
19 Pioneer	60/42	53/43	36/0

7) Capture ratio

D: -55dBm, 1kHz, 22.5 dev, Mono; U: -120dBm, CW; increase U audio drop 1dB, record RF level; increase U audio drop 30dB, record RF level (RF Lev. 1 – RF Lev. 2)/2; test setup 3

Receiver	Capture Ratio dB	Test
01 Delphi	-2.5	Field west
02 Delphi	-2.0	ATTC laboratory
03 Delphi	SF	Field east
05 Technics	-2.8	ATTC laboratory
06 Technics	-4.1	Field compatibility
10 Sony	1	ATTC laboratory
11 Sony	SF	Field compatibility
17 Pioneer	-4.0	Field west
18 Pioneer	6.5	ATTC laboratory
19 Pioneer	SF	Field east

8) Selectivity – 1st adjacent 30 dB RMS S/N

See TP; test setup 3

Receiver	Stereo Upper D/U dB	Stereo Lower D/U dB	Test
01 Delphi	-18	-19	Field west
02 Delphi	-22	-16	ATTC laboratory
03 Delphi	SF	SF	Field east
05 Technics	-11	-3	ATTC laboratory
06 Technics	-3	-4	Field compatibility
10 Sony	2	1	ATTC laboratory
11 Sony	SF	SF	Field compatibility
17 Pioneer	-17	-23	Field west
18 Pioneer	-24	-22	ATTC laboratory
19 Pioneer	SF	SF	Field east

9) Selectivity – 2nd adjacent 30 dB RMS S/N

See TP; test setup 3

Receiver	Stereo Upper D/U dB	Stereo Lower D/U dB	Test
01 Delphi	-55	-55	Field west
02 Delphi	-55	-55	ATTC laboratory
03 Delphi	SF	SF	Field east
05 Technics	-55	-55	ATTC laboratory
06 Technics	-55	-55	Field compatibility
10 Sony	-18	-20	ATTC laboratory
11 Sony	SF	SF	Field compatibility
17 Pioneer	-55	-55	Field west
18 Pioneer	-55	-55	ATTC laboratory
19 Pioneer	SF	SF	Field east

Note: A D/U of –55dB is the test bed limit.

10) (SF) Selectivity – 1st adjacent 50 dB RMS S/N

See TP; test setup 3

Receiver	Stereo Upper D/U dB	Stereo Lower D/U dB	Test
01 Delphi	-13	-18	Field west
02 Delphi	-18	-14	ATTC laboratory
03 Delphi	-21	-15	Field east
05 Technics	1	10	ATTC laboratory
06 Technics	10	9	Field compatibility
10 Sony	20	21	ATTC laboratory
11 Sony	18	23	Field compatibility
17 Pioneer	-12	-18	Field west
18 Pioneer	-19	-17	ATTC laboratory
19 Pioneer	-23	-11	Field east

11) (SF) Selectivity – 2nd adjacent 50 dB RMS S/N

See TP; test setup 3

Receiver	Stereo Upper D/U dB	Stereo Lower D/U dB	Test
01 Delphi	-55	-55	Field west
02 Delphi	-55	-55	ATTC laboratory
03 Delphi	SF	SF	Field east
05 Technics	-48	-45	ATTC laboratory
06 Technics	-43	-43	Field compatibility
10 Sony	-7	-11	ATTC laboratory
11 Sony	-9	-12	Field compatibility
17 Pioneer	-55	-55	Field west
18 Pioneer	-55	-55	ATTC laboratory
19 Pioneer	-55	-55	Field east

Note: A D/U of –55dB is the test bed limit.

12) Selectivity – 3rd adjacent 50 dB RMS S/N

See TP; test setup 3

Receiver	Stereo Upper D/U dB	Stereo Lower D/U dB	Test
01 Delphi	-55	-55	Field west
02 Delphi	-55	-55	ATTC laboratory
03 Delphi	SF	SF	Field east
05 Technics	-48	-45	ATTC laboratory
06 Technics	-45	-43	Field compatibility
10 Sony	-26	-22	ATTC laboratory
11 Sony	SF	SF	Field compatibility
17 Pioneer	-55	-55	Field west
18 Pioneer	-55	-55	ATTC laboratory
19 Pioneer	SF	SF	Field east

Note: A D/U of –55dB is the test bed limit.

13) 10.7 MHz rejection (no implications from IBOC)

14) 10.7 MHz intermodulation (FCC Taboo)

D -45 dBm; target S/N 50 dB RMS; see TP

Receiver	10.6 MHz D/U dB	10.7 MHz D/U dB	Test
01 Delphi	-55	-55	Field west
02 Delphi	-55	-55	ATTC laboratory
03 Delphi	SF	SF	Field east
05 Technics	-19	-19	ATTC laboratory
06 Technics	-19	-20	Field compatibility
10 Sony	-4	0	ATTC laboratory
11 Sony	SF	SF	Field compatibility
17 Pioneer	-39	-35	Field west
18 Pioneer	-40	-36	ATTC laboratory
19Pioneer	SF	SF	Field east

Note: A D/U of –55dB is the test bed limit.

15) Local oscillator interference

U 94.1MHz +10.6MHz or 10.7MHz; D Pilot only –45 dBm; target 50 dB S/N; see TP

Receiver	10.6 MHz D/U dB	10.7 MHz D/U dB	Test
01 Delphi	-55	-55	Field west
02 Delphi	-55	-55	ATTC laboratory
03Delphi	SF	SF	Field east
05 Technics	-16	-21	ATTC laboratory
06 Technics	-15	-21	Field compatibility
10 Sony	1	6	ATTC laboratory
11 Sony	1	4	Field compatibility
17 Pioneer	-36	-28	Field west
18 Pioneer	-37	-27	ATTC laboratory
19 Pioneer	-38	-30	Field east

Note: A D/U of –55dB is the test bed limit.

16) (SF) Intermodulation

Three tone receiver performance with IM signals at 800kHz and 1600kHz above desired.; see TP

D = -47 dBm:

Receiver	D only S/N WQP dB	-10 dB D/U S/N WQP dB	-20 dB D/U S/N WQP dB	-30 dB D/U S/N WQP dB	Test
01 Delphi	59	58	50	42	Field west
02 Delphi	59	58	51	43	ATTC laboratory
03 Delphi	57	57	52	47	Field east
05 Technics	59	41	13	2	ATTC laboratory
06 Technics	60	47	18	3	Field compatibility
10 Sony	52	10	1	0	ATTC laboratory
11 Sony	52	8	0	0	Field compatibility
17 Pioneer	55	54	52	44	Field west
18 Pioneer	56	55	53	45	ATTC laboratory
19 Pioneer	56	56	54	43	Field east

D = –62 dBm:

Receiver	D only S/N WQP dB	-10 dB D/U S/N WQP dB	-20 dB D/U S/N WQP dB	-30 dB D/U S/N WQP dB	Test
01 Delphi	52	51	49	43	Field west
02 Delphi	52	51	50	44	ATTC laboratory
03 Delphi	48	48	48	47	Field east
05 Technics	56	55	43	14	ATTC laboratory
06 Technics	55	54	46	17	Field compatibility
10 Sony	49	33	3	0	ATTC laboratory
11 Sony	49	30	2	0	Field compatibility
17 Pioneer	49	49	48	44	Field west
18 Pioneer	50	50	50	46	ATTC laboratory
19 Pioneer	49	49	49	47	Field east

17) (SF) Narrowband noise sensitivity

D/U at 45dB target S/N; receiver stereo; D –62dBm; see TP

Receiver	-190 kHz D/U dB	-114 kHz D/U dB	Center Channel D/U dB	+114 kHz D/U dB	+190 kHz D/U dB
01 Delphi	-20	-2	24	1	-19
02 Delphi	-20	4	22	3	-13
03 Delphi	-19	1	24	-2	-20
05 Technics	14	37	26	33	2
06 Technics	2	31	20	34	8
10 Sony	36	47	34	48	35
11 Sony	36	47	27	44	30
17 Pioneer	-15	4	27	4	-15
18 Pioneer	-18	2	26	1	-19
19 Pioneer	-16	6	25	-1	-19

Appendix E –
FM IBOC system evaluation criteria

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Evaluation of the iBiquity Digital Corporation IBOC System

Part 1 – FM IBOC

EVALUATION CRITERIA - DIGITAL PERFORMANCE[1]:

Unimpaired audio quality – the fundamental audio quality of the IBOC system. This assessment is to be made with respect to the audio quality of the existing analog broadcasting service compared to the appropriate analog reference.

Service area – the geographical area surrounding the transmit station which can be expected to receive a listenable (usable) radio signal. The service area should take into account the impact of interference from co-channel, 1st-adjacent, and 2nd-adjacent channel signals.

Durability – characterized by an IBOC system design's ability to withstand impairments to the RF channel.

Acquisition performance – the characteristics of how a receiver "locks on" to a radio signal, primarily acquisition time (the elapsed time between tuning to a channel and when the audio on that channel is first heard).

Auxiliary data capacity[2] – characteristics of the data capacity supported by an IBOC system in excess of that needed to deliver the IBOC audio signal, including available throughput, nature of capacity (opportunistic versus continuously available), and transmission quality and durability through the channel (bit error rate and/or other relevant digital data transmission metrics as a function of impairments).

Behavior as signal degrades – how an IBOC system's blend function is able to prevent abrupt loss of the signal at the edge of coverage. Note that, due to the complexities of RF signal propagation, "edge of coverage" performance may be experienced throughout a station's service area and is not restricted simply to regions near or beyond the theoretical protected contour.

Stereo separation – the amount of stereo separation present in the IBOC audio signal, and how it varies as a function of channel and received signal conditions.

Flexibility[3] – represents the potential of an IBOC system to be adapted by broadcasters and manufacturers to meet the needs of listeners and consumers, both present and future.

EVALUATION CRITERIA - COMPATIBILITY:

Host analog signal impact – changes in performance of a host analog signal (main channel audio and any subcarriers) as a result of the presence of the IBOC digital signal energy associated with that host.

Non-host analog signal impact – changes in the performance of a (desired) analog signal (main channel audio and any subcarriers) as a result of the presence of interfering IBOC signals. Interfering signals of interest include co-channel, 1st, and 2nd adjacent channel signals, individually and in combinations.

[1] All digital performance criteria should assess the relative audio quality of the digital system versus existing analog audio quality.
[2] Not currently being tested.
[3] Primarily addressed in system description portion of submission; test results not expected to provide direct evidence of system flexibility.

Appendix F –
FM IBOC system evaluation matrix

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Evaluation of the iBiquity Digital Corporation IBOC System

Part 1 – FM IBOC

Notes:

- A checkmark ("✓ ") indicates that the results from a particular test are expected to apply to the indicated evaluation criteria.
- Test A (Calibration) provides a quality check on system testing as a whole and is not used directly for system evaluation.

<table>
<tr><th colspan="2"></th><th colspan="7">DIGITAL PERFORMANCE</th><th colspan="2">COMPATIBILITY</th></tr>
<tr><th>TEST</th><th>DESCRIPTION</th><th>UNIMPAIRED AUDIO QUALITY</th><th>SERVICE AREA</th><th>DURA-BILITY</th><th>ACQ. PERFORM.</th><th>AUX. DATA CAPACITY[4]</th><th>BEHAVIOR AS SIGNAL DEGRADES</th><th>STEREO SEP</th><th>HOST SIGNAL IMPACT</th><th>NON-HOST SIGNAL IMPACT</th></tr>
<tr><td>B</td><td>IBOC system performance with AWGN</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>1)</td><td>Linear channel</td><td rowspan="2"></td><td rowspan="2">✓</td><td rowspan="2">✓</td><td rowspan="2"></td><td rowspan="2">✓</td><td rowspan="2">✓</td><td rowspan="2">✓</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>2)</td><td>Multipath fading channel</td></tr>
<tr><td>C</td><td>IBOC system performance with special impairments</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>1)</td><td>Impulse noise</td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4">✓</td><td rowspan="4"></td><td rowspan="4">✓</td><td rowspan="4">✓</td><td rowspan="4">✓</td><td rowspan="4"></td><td rowspan="4"></td></tr>
<tr><td>1.5)</td><td>Impulse noise, 1st-adjacent channel interference</td></tr>
<tr><td>2)</td><td>Airplane flutter (Doppler)</td></tr>
<tr><td>2.4)</td><td>Airplane flutter (Doppler), 1st-adjacent channel interference</td></tr>
<tr><td>D</td><td>IBOC ➜ IBOC digital performance</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>1)</td><td>Co-channel interference</td><td rowspan="6"></td><td rowspan="6">✓</td><td rowspan="6">✓</td><td rowspan="6"></td><td rowspan="6">✓</td><td rowspan="6">✓</td><td rowspan="6">✓</td><td rowspan="6"></td><td rowspan="6"></td></tr>
<tr><td>2)</td><td>Single 1st-adjacent channel interference</td></tr>
<tr><td>2.4)</td><td>Simultaneous upper and lower 1st-adjacent channel interference</td></tr>
<tr><td>3)</td><td>Single 2nd-adjacent channel interference</td></tr>
<tr><td>3.4)</td><td>Single 2nd-adjacent channel interference w/1st adj. channel interference</td></tr>
<tr><td>3.5)</td><td>Simultaneous upper and lower 2nd-adjacent channel interference</td></tr>
</table>

[4] See note 2.

		DIGITAL PERFORMANCE							COMPATIBILITY	
TEST	**DESCRIPTION**	**UNIMPAIRED AUDIO QUALITY**	**SERVICE AREA**	**DURA-BILITY**	**ACQ. PERFORM.**	**AUX. DATA CAPACITY[5]**	**BEHAVIOR AS SIGNAL DEGRADES**	**STEREO SEP**	**HOST SIGNAL IMPACT**	**NON-HOST SIGNAL IMPACT**
E	**IBOC ➜ IBOC digital performance in a multipath fading channel**									
1)	Co-channel interference		✓	✓		✓	✓	✓		
2)	Single 1st-adjacent channel interference									
2.4)	Simultaneous upper and lower 1st-adjacent channel interference									
3)	Single 2nd-adjacent channel interference									
3.4)	Single 2nd-adjacent channel interference w/1st adj. channel interference									
3.5)	Simultaneous upper and lower 2nd-adjacent channel interference									
F	**IBOC ➜ Analog compatibility performance**									
1), 3)	Single 1st-adjacent channel interference									✓
2), 4)	Single 2nd-adjacent channel interference									
F/SC	**IBOC ➜ Analog (FM subcarriers) compatibility performance**									
1), 5)	Single 1st-adjacent channel interference, analog subcarriers									✓
3)	Single 1st-adjacent channel interference, digital subcarriers									
2), 6)	Single 2nd-adjacent channel interference, analog subcarriers									
4)	Single 2nd-adjacent channel interference, digital subcarriers									
G	**IBOC ➜ Analog compatibility performance in a multipath fading channel**									
1)	Single 1st-adjacent channel interference									✓

[5] See note 2.

		DIGITAL PERFORMANCE							COMPATIBILITY	
TEST	**DESCRIPTION**	**UNIMPAIRED AUDIO QUALITY**	**SERVICE AREA**	**DURA-BILITY**	**ACQ. PERFORM.**	**AUX. DATA CAPACITY**[6]	**BEHAVIOR AS SIGNAL DEGRADES**	**STEREO SEP**	**HOST SIGNAL IMPACT**	**NON-HOST SIGNAL IMPACT**
H	**IBOC acquisition**									
1)	Acquisition with varying signal level				✓					
I	**IBOC quality**									
1)	Quality transmission test	✓								
J	**IBOC ➜ host Analog compatibility performance**									
1), 2)	Main channel audio performance versus presence or absence of IBOC digital signal energy									
4)	Analog subcarrier performance versus presence or absence of IBOC digital signal energy									
5)	RDS subcarrier performance versus presence or absence of IBOC digital signal energy								✓	
6)	HSSC performance versus presence or absence of IBOC digital signal energy									

[6] See note 2.

Notes:

- A checkmark ("✓ ") indicates that the results from a particular test are expected to apply to the indicated evaluation criteria.
- Test A (Calibration) provides a quality check on system testing as a whole and is not used directly for system evaluation.

		DIGITAL PERFORMANCE							COMPATIBILITY	
TEST	**DESCRIPTION**	**UNIMPAIRED AUDIO QUALITY**	**SERVICE AREA**	**DURA-BILITY**	**ACQ. PERFORM.**	**AUX. DATA CAPACITY[7]**	**BEHAVIOR AS SIGNAL DEGRADES**	**STEREO SEP**	**HOST SIGNAL IMPACT**	**NON-HOST SIGNAL IMPACT**
B	**System performance**									
1)	Low interference and low multipath									
2)	1st-adjacent interference		✓	✓		✓	✓	✓		
3)	2nd-adjacent interference									
C	**Compatibility**									
1)	Host compatibility – main channel audio								✓	
2)	Host compatibility – analog and digital subcarriers									
3)	1st-adjacent channel compatibility									✓

[7] See note 2.

Appendix G –
Discussion of stereo-mono blending in analog receivers

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Evaluation of the iBiquity Digital Corporation IBOC System

Part 1 – FM IBOC

FM stereo automobile radios use a circuit called blend to reduce the audible effects of multipath, adjacent channel interference, and stereo noise. Blending from stereo to mono accomplishes the noise reduction. The choice of blend characteristics is radio manufacturer dependent. Any or all of the following controls the amount of FM stereo blend: RF signal level, 1st adjacent interference, and 2nd through 20th adjacent channel interference. The effects of these blend controlling factors on stereo separations for the two automobile radios used in the IBOC laboratory and field tests are described in this report.

Signal Level Dependent Blend

Table 1 shows the results of stereo separation tests conducted by an independent laboratory with varying levels of RF power at the input of two automobile radios. These radios are the same model used for the IBOC field and laboratory tests. Assuming acceptable stereo to have a separation of 15 dB, the lowest signal level where acceptable stereo can be expected is at a RF power level of -67dBm for both radios. At RF signal levels of –70 dBm and lower, both radios are essentially mono.

Table 1. Signal Level/Stereo Separation
(bold text indicates blending transition region)

AUTOMOBILE RADIO SCENARIO			
LAB RF POWER (DBM)	FIELD STRENGTH AT 30FT ABOVE GROUND (DBU)	SEPARATION (DB)	
		DELPHI	PIONEER
-100	22	0	0
-95	27	0	0
-90	32	0	0
-85	37	0	0
-80	42	0	2
-75	47	3	4
-70	**52**	**7**	**12**
-65	**57**	**17**	**28**
-60	62	37	38
-55	67	31	39
-50	72	31	39

FM Stereo Separation with 1st Adjacent Analog Interferer

Table 2 shows the results of stereo separation tests conducted at four signal levels and four D/U ratios. The table lists the stereo separation for each receiver under varying interference conditions. At signal levels of –62 dBm or stronger and D/U of 6 dB or lower the stereo separation is 28 dB or larger. Only the Pioneer maintained separation at the –62 dBm or stronger signal levels with a D/U of –4 dB or higher. At the –72 dBm and lower signal levels the stereo separation ranged from 0.0 dB to 8.0 dB. Again, assuming acceptable stereo to have a separation of 15 dB or higher, the A-> A D/U ratio of no more than 6 dB and signal level of at least -62 dBm is necessary to produce stereo on the Delphi.

Table 2. FM stereo separation with 1st adjacent analog interference

LAB RF POWER (DBM)	FIELD STRENGTH AT 30FT. ABOVE GROUND (DBU)	STEREO SEPARATION			
		16 DB D/U	6 DB D/U	-4 DB D/U	-14 DB D/U
		SEPARATION DEL/PIO (DB)	SEPARATION DEL/PIO (DB)	SEPARATION DEL/PIO (DB)	SEPARATION DEL/PIO (DB)
-47	75	37/39	37/39	0/39	0/35
-62	60	28/38	28/38	0/38	0/32
-72	50	5/8	5/8	0/8	0/8
-82	40	0/0	0/0	0/0	0/0

FM Stereo Separation with 2nd Adjacent Single Analog Interferer

Table 3 shows the test results of 2nd adjacent stereo separation tests conducted at two signal levels. The Pioneer stereo separation was reduced to 10 dB at the -30 dB D/U at both signal levels. The Delphi lost stereo at the -40 dB D/U.

Table 3. FM stereo separation reduction caused by 2nd adjacent channel

DESIRE SIGNAL LEVEL	D/U –20DB DEL/PIO (DB)	D/U –30DB DEL/PIO (DB)	D/U –40DB DEL/PIO (DB)	D/U –50DB DEL/PIO (DB)
-47dBm	37/37	22/10	5/2	0/0
-62dBm	28/36	18/10	3/2	0/0

FM Stereo Separation with 5th through 20th Adjacent Channels

Table 4 and Table 5 show the results of 5th, 10th, and 20th adjacent A->A channel tests at two signal levels. At the -40 dB D/U the Delphi stereo separation was below 15 dB for 5 of the 6 tests and the Pioneer for 2 of 6 tests. For the -50 dB D/U the best separation was 7 dB for both receivers for all three adjacent channels tested and both signal levels.

Table 4. FM stereo separation controlled by adjacent channels
(bold text indicates blending transition region)

5TH THROUGH 20TH -47 DBM				
ADJACENT CHANNEL	D/U –20DB DEL/PIO (DB)	D/U –30DB DEL/PIO (DB)	D/U –40DB DEL/PIO (DB)	D/U –50DB DEL/PIO (DB)
5th	37/41	29/34	**6/8**	0/2
10th	(not tested)	38/40	**10/19**	2/3
20th	(not tested)	37/40	**19/33**	4/7

Table 5. FM stereo separation controlled by adjacent channels (bold text indicates blending transition region)

5TH THROUGH 20TH -62 DBM				
ADJACENT CHANNEL	D/U –20DB DEL/PIO (DB)	D/U –30DB DEL/PIO (DB)	D/U –40DB DEL/PIO (DB)	D/U –50DB DEL/PIO (DB)
5th	28/36	20/36	**4/8**	0/1
10th	(not tested)	26/36	**6/20**	0/3
20th	(not tested)	27/36	**11/36**	2/7

Temporal Blend

During the laboratory characterization test it was found that the blend decay times for the two automobile radios used for the IBOC tests differed by several seconds. To measure this characteristic on a broader base two automobile radios, a Kenwood and Sony, were added to Delphi and Pioneer for the temporal blend tests. It was found that blend off-to-on time was less than one second for all four radios. The decay time for the Pioneer, Sony, and Kenwood radios was less than one second. The Delphi radio's blend decay time was four seconds long.

Conclusion

The threshold of blend to mono system in the automobile FM stereo radio is manufacturer dependent. The predominant controlling factors vary. The blend decay characteristic for one radio is much longer than the other three radios. The two automobile FM stereo radios selected for the IBOC tests represent a cross section of blend performance.

Appendix H –
Discussion of Differences Between Laboratory and Field Subjective Evaluation Results

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Evaluation of the iBiquity Digital Corporation IBOC System

Part 1 – FM IBOC

The data from the NRSC's FM IBOC compatibility tests seems to indicate that listeners were more critical of interference at a particular D/U ratio when the results came from the laboratory than when they came from the field.[1] To investigate why this might be the case, additional laboratory tests were conducted by the NRSC subsequent to the release of the FM IBOC Test Data Report. These tests included an expanded number of automobile receivers (six), an expanded desired RF input signal range (-47, -62, -72 and -82 dBm), and the D/U ratios +16, +6, -4 and -14 dB. Objective data was collected to show stereo separation and audio signal-to-noise for each receiver at each desired signal level and D/U ratio combination.

iBiquity provided the NRSC with the RF signal levels that were measured at each of the host and first-adjacent field test fixed locations during the NRSC FM IBOC compatibility tests. This data was provided subsequent to the release of the FM IBOC test report, and thus is not found in the report. It, and the specific data points from the post-FM IBOC Test Data Report laboratory results that most closely match each D/U and desired receiver input signal level combination from the field, are summarized in Table H-1 and Table H-2 for the two automobile receivers that were tested in the field.

When the RF signal levels measured in the field are compared with the receiver characterization stereo separation vs. signal level test data (see Appendix D) it is apparent that both automobile receivers were operating in monophonic mode under most field test conditions. However, the laboratory data that was collected during the NRSC FM IBOC compatibility tests was collected at desired signal levels that were considerably higher than the signal levels found in the field, levels at which the receivers would be operating in stereo mode. For example, when the Delphi receiver was measured at the +6 dB D/U ratio in the laboratory during the NRSC FM IBOC compatibility testing, the desired receiver input level was -62 dBm. However, when the same receiver was measured at the same D/U ratio in the field the desired receiver input levels recorded were -61.5, -62.5, -65.5, -74.5, -82.0, -83.5, -85.0, -86.0 and -92.0 dBm. The stereo separation vs. signal level data from the characterization test for the Delphi receiver indicates that the stereo separation at these desired receiver input levels is 31, 31, 16, 3, 0, 0, 0, 0 and 0 dB, respectively. For all of the remaining first adjacent compatibility data points taken in the field with the Delphi receiver (*i.e.*, at D/U ratios that were lower, or more negative, than +6 dB) the stereo separation is predicted to exceed 7 dB at only one desired signal input level. The results for the Pioneer receiver are similar. Its receiver characterization data suggests that, generally speaking, it has slightly more stereo separation over the range of receiver input levels tested in the field, though it is essentially operating in mono at most of these levels.

Thus it appears that in the vast majority of field test locations the receivers were operating in monophonic mode. It also appears that under the +16 dB D/U and -62 dBm desired input signal condition, and under the +6 dB D/U and –62 dBm desired input signal condition (which together accounted for two-thirds of the no-multipath laboratory tests that were subjectively evaluated) both automobile receivers were operating in the stereophonic mode. It appears that the fact that the laboratory tests were generally conducted in stereo while the field tests were generally conducted in mono caused the subjective evaluators to rate the laboratory audio more critically than they rated the field audio. That is, all else being equal, listeners are more likely to detect a particular level of interference when the desired signal is stereo than when the desired signal is mono.

[1] For example, at the +6 dB D/U ratio in the field listeners rated a station's analog audio quality with speech programming on the Delphi receiver at 2.5 MOS ±0.28 when the undesired signal was a first adjacent channel IBOC signal. Under the same conditions in the laboratory, however, listeners rated the desired station's analog audio quality at 2.2 MOS ±0.25 (lower first adjacent interferer) and 2.2 MOS ±0.21 (upper first adjacent interferer). Similar situations are found throughout the test results. Some differences are more pronounced, and some are not. FM IBOC Test Data Report, Appendix I.

This data suggests that both results (those collected in the lab and those collected in the field) are accurate representations of how listeners will perceive interference at the specific D/U ratio and receiver input signal levels tested. Many of the data points taken in the field are actually providing information about a different reception condition than the corresponding data points taken in the laboratory for the same D/U ratio because of the difference in receiver input signal level. Thus, rather than using the laboratory and field tests to corroborate one another, it is more appropriate to use them to complement one another because, together, they provide information about more reception conditions than either of them do alone.

Table H-1. Delphi Automobile Radio First Adjacent Field and Laboratory Data

	Field Test Data						Stereo Separation at Field RF Level According to RX Characterization (dB)	Post FM IBOC Test Data Report Laboratory Test Data		Proximity of PFITDR Lab Data Point to Field	
Reference Number	1st Adj. D/U (dB)	Location Number	Station Call	Desired Frequency (MHz)	Format	RF Level @ RX Input (dBm)		Stereo Separation A->A / D[1]-A (dB)	Signal Level / 1st Adj. D/U	RF Level (Lab minus Field, dB)	D/U Ratio (Lab minus Field, dB)
1	6U	1	WMRA	90.7	Class/NPR	-61.5	31	28 / 28	-62 dBm / +6 dB	-0.5	0
2	6U	2	WMRA	90.7	Class	-65.5	16	28 / 28	-62 dBm / +6 dB	+3.5	0
3	6L	3	WHFC	91.1	Folk	-62.5	31	28 / 28	-62 dBm / +6 dB	+0.5	0
4	6L	1	WFLS	93.3	Country	-74.5	03	05 / 05	-72 dBm / +6 dB	+2.5	0
5	6L	2	WFLA	93.3	Country	-85.0	00	00 / 00	-82 dBm / +6 dB	+3.0	0
6	6U	3	WDSD	92.9	Country/Speech	-82.0	00	00 / 00	-82 dBm / +6 dB	0.0	0
7	6L	1	WMGK	102.9	Rock	-83.5	00	00 / 00	-82 dBm / +6 dB	+1.5	0
8	6L	2	WMGK	102.9	Country	-92.0	00	00 / 00	-82 dBm / +6 dB	+10.0	0
9	6L	3	WMGK	102.9	Rock	-86.0	00	00 / 00	-82 dBm / +6 dB	+4.0	0
10	-14L	1	WFLS	93.3	Country	-75.0	03	00 / 00	-72 dBm / -14 dB	+3.0	0
11	-11L	2	WFLS	93.3	Country	-72.5	04	00 / 00	-72 dBm / -14 dB	+0.5	-3
12	-10L	3	WFLS	93.3	Country	-70.5	07	00 / 00	-72 dBm / -14 dB	-1.5	-4
13	-8L	4	WFLS	93.3	Country	-70.0	07	00 / 00	-72 dBm / -4 dB	-2.0	+4
14	-6L	5	WFLS	93.3	Country	-71.0	07	00 / 00	-72 dBm / -4 dB	-1.0	+2
15	-4L	6	WFLS	93.3	Country	-69.5	07	00 / 00	-72 dBm / -4 dB	-2.5	0
16	-14L	7	WFLS	93.3	Country	-85.5	00	00 / 00	-82 dBm / -14 dB	+3.5	0
17	-13L	8	WFLS	93.3	Country	-77.5	01	00 / 00	-82 dBm / -14 dB	-4.5	-1
18	-18L	9	WFLS	93.3	Country	-75.5	02	00 / 00	-72 dBm / -14 dB	+3.5	+4
19	-8L	10	WFLS	93.3	Country	-74.5	03	00 / 00	-72 dBm / -4 dB	+2.5	+4
20	-6L	11	WFLS	93.3	Country	-74.5	03	00 / 00	-72 dBm / -4 dB	+2.5	+2
21	-4L	12	WFLS	93.3	Country	-74.0	02	00 / 00	-72 dBm / -4 dB	+2	0
22	-9U	1	WMRA	90.7	Class/NPR	-77.0	01	00 / 00	-72 dBm / -14 dB	+5	-5
23	-6U	2	WMRA	90.7	Class/NPR	-75.5	03	00 / 00	-72 dBm / -4 dB	+3.5	+2
24	-4U	3	WMRA	90.7	Class/NPR	-65.5	17	00 / 00	-62 dBm / -4 dB	+3.5	0

[1]For the Post FM IBOC Test Data Report Laboratory Tests, the FM IBOC signal was simulated with AWGN.

Level Dependent Blend:

1. Four desired RF test levels produced stereo separation of 16dB or higher.
2. Twenty desired RF test levels produced stereo separation 7dB or lower.

Interference and Level Dependent Blend:

1. With 1st adjacent analog interference three tests produced stereo separation of 15dB or more.
2. For these tests scenarios the IBOC did not change stereo separation.

Table H-2. Pioneer Automobile Radio First Adjacent Field and Laboratory Data

	Field Test Data						Stereo Separation at Field RF Level According to RX Characterization (dB)	Post FM IBOC Test Data Report Laboratory Test Data		Proximity of PFITDR Lab Data Point to Field	
Reference Number	1st Adj. D/U (dB)	Location Number	Station Call	Desired Frequency (MHz)	Format	RF Level @ RX Input (dBm)		Stereo Separation A->A / D[1]-A (dB)	Signal Level / 1st Adj. D/U	RF Level (Lab minus Field, dB)	D/U Ratio (Lab minus Field, dB)
1	6U	1	WMRA	90.7	Class/NPR	-61.5	35	38 / 37	-62 dBm / +6 dB	-0.5	0
2	6U	2	WMRA	90.7	Class	-65.5	27	38 / 37	-62 dBm / +6 dB	+3.5	0
3	6L	3	WHFC	91.1	Folk	-62.5	34	38 / 37	-62 dBm / +6 dB	+0.5	0
4	6L	1	WFLS	93.3	Country	-74.5	04	08 / 08	-72 dBm / +6 dB	+2.5	0
5	6L	2	WFLA	93.3	Country	-85.0	00	02 / 02	-82 dBm / +6 dB	+3.0	0
6	6U	3	WDSD	92.9	Country/Speech	-82.0	02	02 / 02	-82 dBm / +6 dB	0.0	0
7	6L	1	WMGK	102.9	Rock	-83.5	01	02 / 02	-82 dBm / +6 dB	+1.5	0
8	6L	2	WMGK	102.9	Country	-92.0	00	02 / 02	-82 dBm / +6 dB	+10.0	0
9	6L	3	WMGK	102.9	Rock	-86.0	00	02 / 02	-82 dBm / +6 dB	+4.0	0
10	-14L	1	WFLS	93.3	Country	-75.0	04	05 / 00	-72 dBm / -14 dB	+3.0	0
11	-11L	2	WFLS	93.3	Country	-72.5	10	05 / 00	-72 dBm / -14 dB	+0.5	-3
12	-10L	3	WFLS	93.3	Country	-70.5	12	05 / 00	-72 dBm / -14 dB	-1.5	-4
13	-8L	4	WFLS	93.3	Country	-70.0	12	08 / 08	-72 dBm / -4 dB	-2.0	+4
14	-6L	5	WFLS	93.3	Country	-71.0	11	08 / 08	-72 dBm / -4 dB	-1.0	+2
15	-4L	6	WFLS	93.3	Country	-69.5	12	08 / 08	-72 dBm / -4 dB	-2.5	0
16	-14L	7	WFLS	93.3	Country	-85.5	01	01 / 00	-82 dBm / -14 dB	+3.5	0
17	-13L	8	WFLS	93.3	Country	-77.5	03	01 / 00	-82 dBm / -14 dB	-4.5	-1
18	-18L	9	WFLS	93.3	Country	-75.5	04	05 / 00	-72 dBm / -14 dB	+3.5	+4
19	-8L	10	WFLS	93.3	Country	-74.5	04	05 / 00	-72 dBm / -4 dB	+2.5	+4
20	-6L	11	WFLS	93.3	Country	-74.5	04	08 / 08	-72 dBm / -4 dB	+2.5	+2
21	-4L	12	WFLS	93.3	Country	-74.0	04	08 / 08	-72 dBm / -4 dB	+2	0
22	-9U	1	WMRA	90.7	Class/NPR	-77.0	05	08 / 08	-72 dBm / -14 dB	+5	-5
23	-6U	2	WMRA	90.7	Class/NPR	-75.5	03	08 / 08	-72 dBm / -4 dB	+3.5	+2
24	-4U	3	WMRA	90.7	Class/NPR	-65.5	26	38 / 33	-62 dBm / -4 dB	+3.5	0

[1]For the Post FM IBOC Test Data Report Laboratory Tests, the FM IBOC signal was simulated with AWGN.

Level Dependent Blend:

1. Four desired RF levels produced stereo separation of 26dB or higher.
2. Twenty desired RF levels produced stereo separation of 12dB or lower.

Interference and Level Dependent Blend:

1. With 1st adjacent analog interference four tests produced stereo separation of 15dB or higher.
2. For these scenarios the IBOC made little change in stereo separation.

Appendix I –
NRSC 1st-adjacent channel study

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Evaluation of the iBiquity Digital Corporation IBOC System

Part 1 – FM IBOC

FIRST ADJACENT CHANNEL IBOC INTERFERENCE DEMONSTRATION PREPARED FOR NATIONAL RADIO SYSTEMS COMMITTEE

INTRODUCTION

Evaluation of first adjacent channel compatibility of future hybrid IBOC FM stations with existing analog FM broadcast stations was an area of significant emphasis in the National Radio System Committee (NRSC) testing of iBiquity's IBOC system. This study was undertaken to demonstrate a methodology for evaluating the impact of future IBOC operations on the analog operation of existing FM stations. The results are not intended to be representative of the impact on all stations, since only six stations could be analyzed under the time constraints for the study, but rather are intended to illustrate how the subjective data collected in the NRSC testing can be applied to study the potential IBOC impact on individual stations.

The parameters employed in the study are based on subjective data for a speech formatted FM station received on an automobile radio. The speech format is the most demanding test for IBOC compatibility. The predicted IBOC first adjacent impact on station coverage for automobile radios receiving other station formats would likely be lower or indiscernible.

The population data employed in the study are from 1990 US Census and do not represent actual station listeners. Similarly, the interference predictions and percentages shown in the tabulations are referenced to the US

Census data and do not represent impact on actual station listeners. As a general rule, station listeners are concentrated near the core of a station's service area. Therefore, predicted IBOC interference near the outskirts of a station's service area should not impact a significant number of station listeners.

STATIONS STUDIED

The six stations employed in the study were selected to reflect a variety of station classes, allocation scenarios, and terrain conditions. The following table lists the stations studied and the significant conditions that apply to each.

													Terrain Conditions		
Call Sign	Channel/ Class	ERP (kW)	HAAT (meters)	City, State	Noncommercial	Commercial	Directional	Grandfathered Super Power	Grandfathered Short Spaced	Fully Spaced (Or Nearly)	Short Spaced (73.215)	Significant Terrain Advantage	Flat	Moderate	Rough
WETA	215B	75	186	Washington, DC	X			X						X	
KEGL	246C	100	508	Fort Worth, TX		X				X			X		
WKKJ	227B	50	106	Chillicothe, OH		X			X				X		
KFRR	281B	17	260	Woodlake, CA		X				X		X	X		X
WDCZ	274A	6	100	Webster, NY		X	X				X			X	
KZFO	221B1	25	95	Madera, CA		X				X			X		X

Several of the stations conditions are noteworthy. WETA was selected because it is a noncommercial station and is grandfathered with facilities in excess of the maximum permitted for a Class B station. Noncommercial stations are protected to the FCC predicted 60 dBu F(50,50) contour regardless of class based on their licensed facilities. KFRR was selected because it is has a significant height above average terrain advantage to the south and west in the direction of two first adjacent stations.

WDCZ is an example of an extreme interference condition. WDCZ is short spaced to WTSS, Buffalo, New York, pursuant to Section 73.215 of the FCC Rules. In addition, WTSS is a Class B station grandfathered with facilities of 110 kilowatts ERP and antenna radiation center HAAT of 408 meters which are far in excess of the maximum facilities of 50 kilowatts and 150 meters permitted for a Class B station. Thus, the interference predicted to WDCZ from WTSS in the studies herein represents an extreme case and is not representative of the interference predicted to Class A stations or stations employing contour protection pursuant to Section 73.215 of the FCC Rules.

METHODOLOGY AND STUDY PARAMETERS

The First Adjacent Channel IBOC Interference Demonstration is based on an adapted version of the Federal Communications Commission program for calculating service and interference areas for digital television. The program calculates field strength and interference conditions for analog and IBOC operations over a grid of nearly square cells. A detailed description of the study methodology provided by the software contractor, Techware Inc., is attached.

The desired-to-undesired (D/U) signal strength ratios for first adjacent hybrid IBOC-to-analog and analog-to-analog employed in the studies were derived from subjective data results from the NRSC testing. The subjective data results were analyzed by Dave Wilson of the Consumer Electronics Association for the NRSC. Based on the subjective analysis, a hybrid IBOC-to-analog D/U ratio of 6 dB applies for a speech formatted station received on an automobile radio. The results of the subjective tests suggest that the analog-to-analog D/U ratio for a speech formatted station is more negative than -4 dB. However, the limited D/U data collected does not allow the D/U ratio to be precisely determined. Therefore, an analog-to-analog D/U ratio of -4 dB was used in the analysis.

An analog-to-analog cochannel D/U ratio of 20 dB from the FCC Rules was used to evaluate existing cochannel analog interference. It was unnecessary to evaluate cochannel hybrid IBOC-to-analog interference since interference from the analog portion of a hybrid IBOC operation would mask any interference from the IBOC portion.

For each station, two studies were performed using different limiting contours. The limiting contours were determined using the FCC's contour prediction methodology. These limiting contours define the boundary of the study. The first limiting contour is the protected contour for the station under study. The second study was limited at the 40 dBu contour, which was selected as the rough limit of automobile radio reception.

RESULTS

The results of the studies for each station consist of a tabulation detailing the populations and areas for the various conditions studied and two maps, one for each of the limiting contours employed. Each of the maps depicts the predicted areas of existing cochannel and first adjacent channel analog interference as well as potential IBOC interference from first adjacent channel hybrid IBOC stations. The maps also show the Longley-Rice predicted signal strength within the limiting FCC contour at locations where no interference is predicted. The maps are intended to be used only as a guide to determine general areas where interference may occur. Since signal propagation is statistical in nature and propagation models are not capable of accounting for all the factors that may affect coverage, the maps should not be used as an absolute determination of coverage or interference.

Evaluation of IBOC Impact on Analog FM Service
November 13, 2001

Methodology

An In Band on Channel digital transmission system for the FM broadcast band (IBOC) has been proposed by iBiquity Digital Corporation. As part of the evaluation to determine the feasibility of the proposed system an analysis was performed to assess the predicted impact of the system on existing analog reception.

The evaluation was based on the following parameters and assumptions.

1. Each existing full service FM broadcast station will implement the IBOC system.
2. The power and antenna height for each station was as listed in the FCC's FM broadcast station database. In the case where multiple records existed for the same station the parameters were selected based on the following hierarchy: Construction Permit, License, Application. The only exceptions to this being for the six stations that were evaluated. Their parameters were as provided by the NAB's consultant.
3. Vertical polarization was assumed for both transmit and receive antennas
4. Any directional transmit horizontal antenna patterns listed in the FCC database were considered
5. No vertical antenna patterns were considered
6. The receive antenna for Longley-Rice analyses was assumed to be non-directional and 2 meters above ground level
7. Protected contours were computed using the FCC F50/50 curves and the height above average terrain for the standard evenly spaced 8 radials.
8. Within the protected contours service and interfering fields were computed using the Longley-Rice propagation model.
9. Longley-Rice service fields were computed on the basis of F50/50 while interfering field computations were for F50/10.
10. Population counts based on 1990 census data
11. Terrain data was 3 second USGS data
12. Longley-Rice flags indicating potentially unreliable predictions were ignored (Experience has indicated that these predictions are usually in line with what is expected for the point in question)
13. The potential interfering stations that were considered in the Longley-Rice analysis were determined by selecting stations that are within 1.5 times the normal separation distance required by the FCC. Analog stations on the same and 1st adjacent channels were selected. Potential IBOC interference was calculated from those stations whose analog channel is on the 1st adjacent channel from the protected station.

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14. Required desired-to-undesired (D/U) field strengths were as provided by the NAB's consultant (20 dB analog-to-analog co-channel, -4 dB analog-to-analog 1st adjacent channel, and 6 dB 1st adjacent channel IBOC-to-analog. No IBOC-to-analog co-channel evaluation was made since it is assumed that any interference would always be masked by the analog-to-analog interference)
15. Two sets of analyses were performed. The first set assumed the field strength required for service was the same as the FCC protected contour for the class of station being analyzed. The second set assumed 40 dBμ as the field strength required for service.

The actual prediction of coverage and interference within the protected contours was determined by dividing the area into a grid of essentially square cells 0.5 km on a side (0.25 square km). For each cell a determination was made as to the census blocks (the smallest subdivision of census data) that were within that cell and then a geographic point for calculation purposes was determined by finding the centroid of the population within the cell. This grid methodology is the same as the FCC used in its DTV planning.

At each grid point the predicted field strength for the protected station and the potential interfering stations was made using the Longley-Rice propagation model. At each point where the service prediction was above the service threshold a determination was made of the ratio of the desired signal to each potential interfering signal (D/U ratio) to determine if interference would be expected for that cell.

From the analysis four service predictions are provided. The first is the population and area within the predicted contour and the second is the population and area that is not lost to terrain obstructions (as determined by the Longley-Rice model). The next is the population and area not lost to terrain and/or analog interference (service without IBOC) and finally the population and area considering all terrain and interference losses (with IBOC).

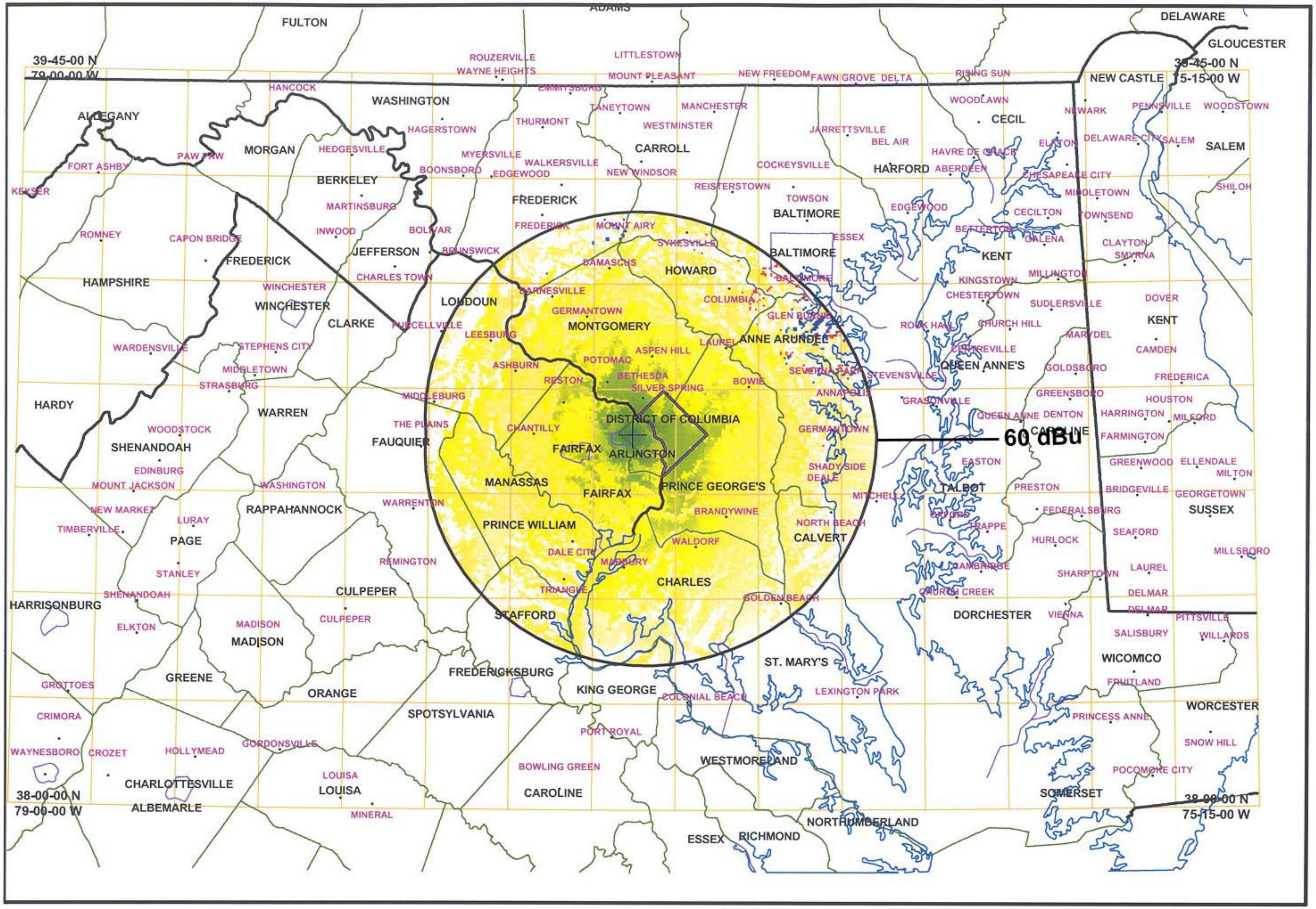
For each of the stations considered two maps have been provided, one assuming the FCC protected contour as the required level of service and a second based on 40 dBμ. The 40 dBμ map also shows the FCC protected contour. Points on each map where the service prediction was at or above the assumed minimum and the D/U ratio was above the level at which interference is expected are indicated by a sliding color scale that depicts the predicted field strength at the point. Points where the D/U ratio indicates interference is expected are denoted in either red (analog interference) or blue (IBOC interference). It should be noted that the blue areas indicating IBOC interference would show service in the absence of IBOC. In other words the IBOC interference is not masking any analog interference.

WETA WASHINGTON, DC CH 215B
Site location 38 53 30 77 07 55
Power 75.00000
RCAMSL 252.000
Antenna Rotation 0.0 Antenna ID 0
FCC Predicted contour 60 dBu
Station type Analog

	Within FCC Protected Contour (60 dBu)					
	Population	Area (Sq km)	Percent Change From Terrain Limited Population	Percent Change From Terrain Limited Area	Differential In Percent Change For Population IBOC-OFF/IBOC-ON	Differential In Percent Change For Area IBOC-OFF/IBOC-ON
Within FCC Predicted Contour	4,580,172	11,212.53				
Within Terrain Limited (Longley-Rice)	4,289,282	9,663.92	0.00	0.00		
Interference limited service without IBOC	4,260,075	9,636.49	-0.68	-0.28		
Interference limited service with IBOC	4,237,066	9,603.08	-1.22	-0.63	-0.54	-0.35

WETA WASHINGTON, DC CH 215B
Site location 38 53 30 77 07 55
Power 75.00000
RCAMSL 252.000
Antenna Rotation 0.0 Antenna ID 0
FCC predicted contour 40 dBu
Station type Analog

	Within and Beyond FCC Protected Contour to FCC Predicted 40 dBu Contour					
	Population	Area (Sq km)	Percent Change From Terrain Limited Population	Percent Change From Terrain Limited Area	Differential In Percent Change For Population IBOC-OFF/IBOC-ON	Differential In Percent Change For Area IBOC-OFF/IBOC-ON
Within FCC Predicted Contour	7,072,619	36,822.02				
Within Terrain Limited (Longley-Rice)	6,746,709	31,448.85	0.00	0.00		
Interference limited service without IBOC	5,763,553	23,779.69	-14.57	-24.39		
Interference limited service with IBOC	5,508,418	20,792.02	-18.35	-33.89	-3.78	-9.50



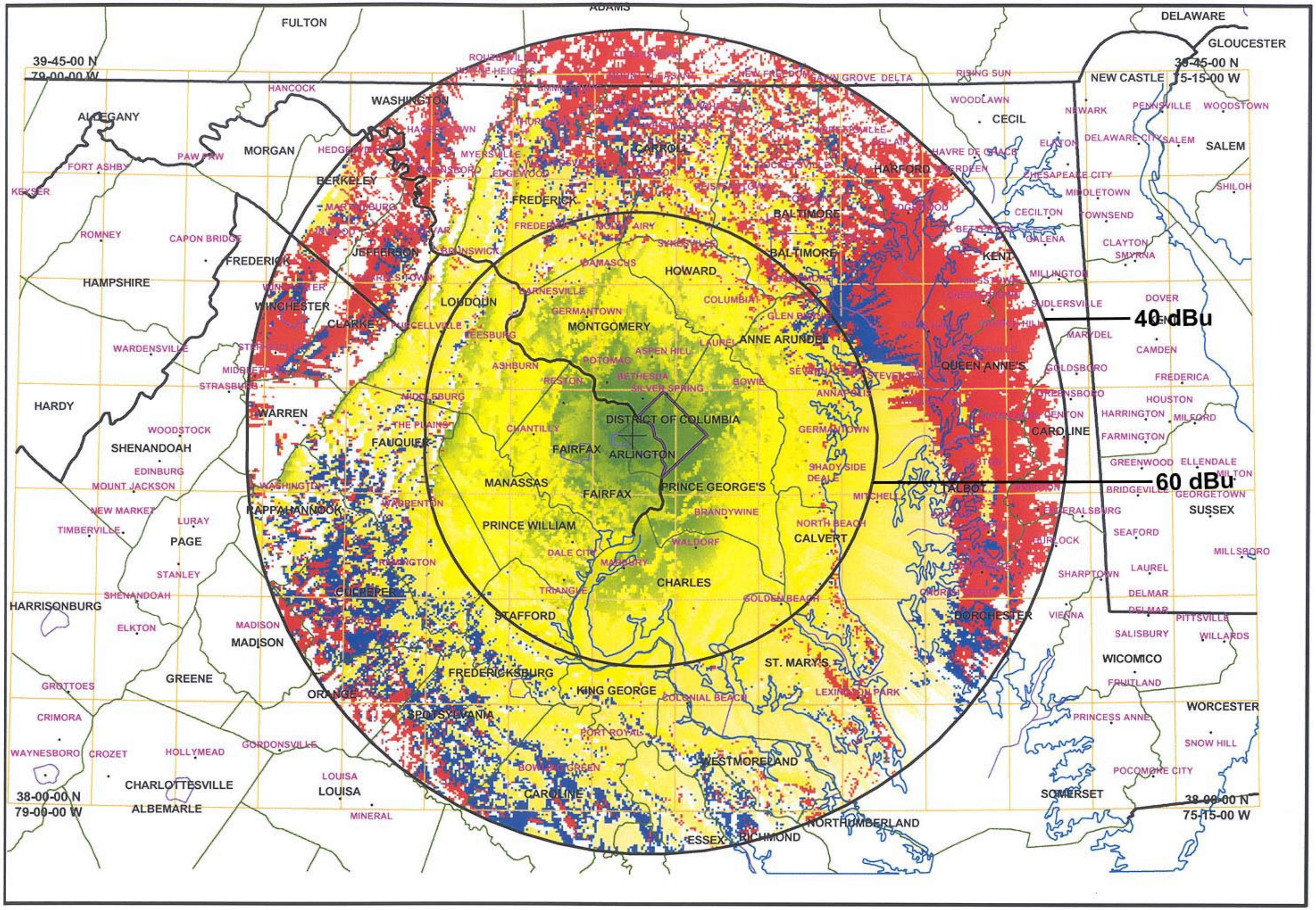
WETA WASHINGTON DC Analog FM Channel 215
Interference: Analog = RED Digital = BLUE

Within FCC Protected Contour (60 dBu)

Prepared for NAB
Prepared by TechWare, Inc. Chantilly, VA 703-222-5842

0 KM 100

146.08 dBu 103.04 dBu 60 dBu
Predicted Longley-Rice Field



WETA WASHINGTON DC Analog FM Channel 215

Interference: Analog = RED Digital = BLUE

Within and Beyond FCC Protected Contour to FCC Predicted 40 dBu

Prepared for NAB

Prepared by TechWare, Inc. Chantilly, VA 703-222-5842

0 KM 100

143.68 dBu 91.84 dBu 40 dBu

Predicted Longley-Rice Field

KEGL FORT WORTH, TX CH 246C
Site location 32 35 19 96 58 05
Power 100.00000
RCAMSL 697.000
Antenna Rotation 0.0 Antenna ID 0
FCC Predicted contour 60 dBu
Station type Analog

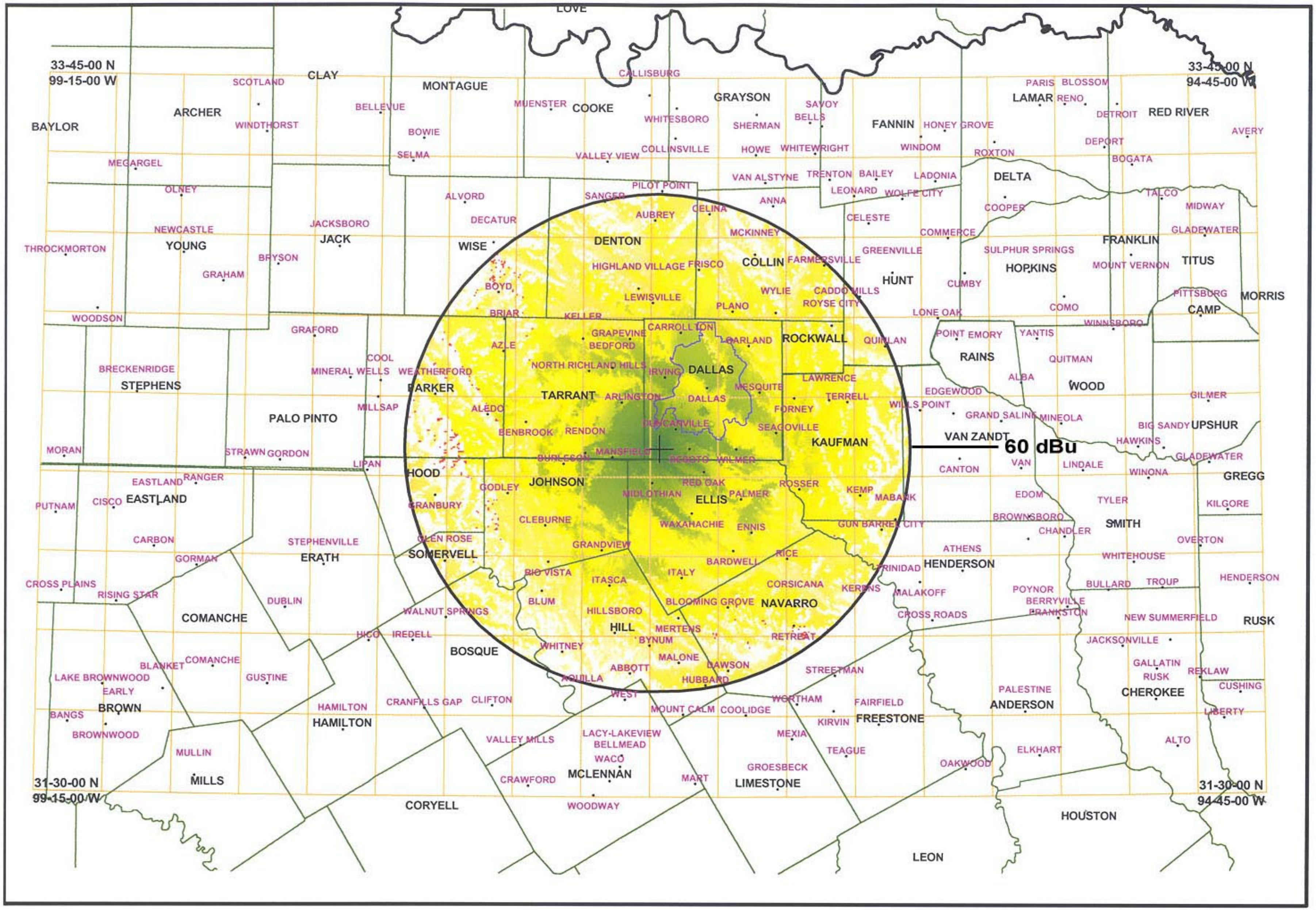
Within FCC Protected Contour (60 dBu)

	Population	Area (Sq km)	Percent Change From Terrain Limited Population	Percent Change From Terrain Limited Area	Differential In Percent Change For Population IBOC-OFF/IBOC-ON	Differential In Percent Change For Area IBOC-OFF/IBOC-ON
Within FCC Predicted Contour	3,993,478	23,812.18				
Within Terrain Limited (Longley-Rice)	3,940,454	21,132.26	0.00	0.00		
Interference limited service without IBOC	3,939,849	21,071.47	-0.02	-0.29		
Interference limited service with IBOC	3,939,849	21,071.47	-0.02	-0.29	0.00	0.00

KEGL FORT WORTH, TX CH 246C
Site location 32 35 19 96 58 05
Power 100.00000
RCAMSL 697.000
Antenna Rotation 0.0 Antenna ID 0
FCC predicted contour 40 dBu
Station type Analog

Within and Beyond FCC Protected Contour to FCC Predicted 40 dBu Contour

	Population	Area (Sq km)	Percent Change From Terrain Limited Population	Percent Change From Terrain Limited Area	Differential In Percent Change For Population IBOC-OFF/IBOC-ON	Differential In Percent Change For Area IBOC-OFF/IBOC-ON
Within FCC Predicted Contour	4,703,497	65,265.70				
Within Terrain Limited (Longley-Rice)	4,642,371	57,753.20	0.00	0.00		
Interference limited service without IBOC	4,241,562	37,823.20	-8.63	-34.51		
Interference limited service with IBOC	4,229,247	36,726.70	-8.90	-36.41	-0.27	-1.90



KEGL FORT WORTH TX Analog FM Channel 246

Interference: Analog = RED Digital = BLUE

Within FCC Protected Contour (60 dBu)

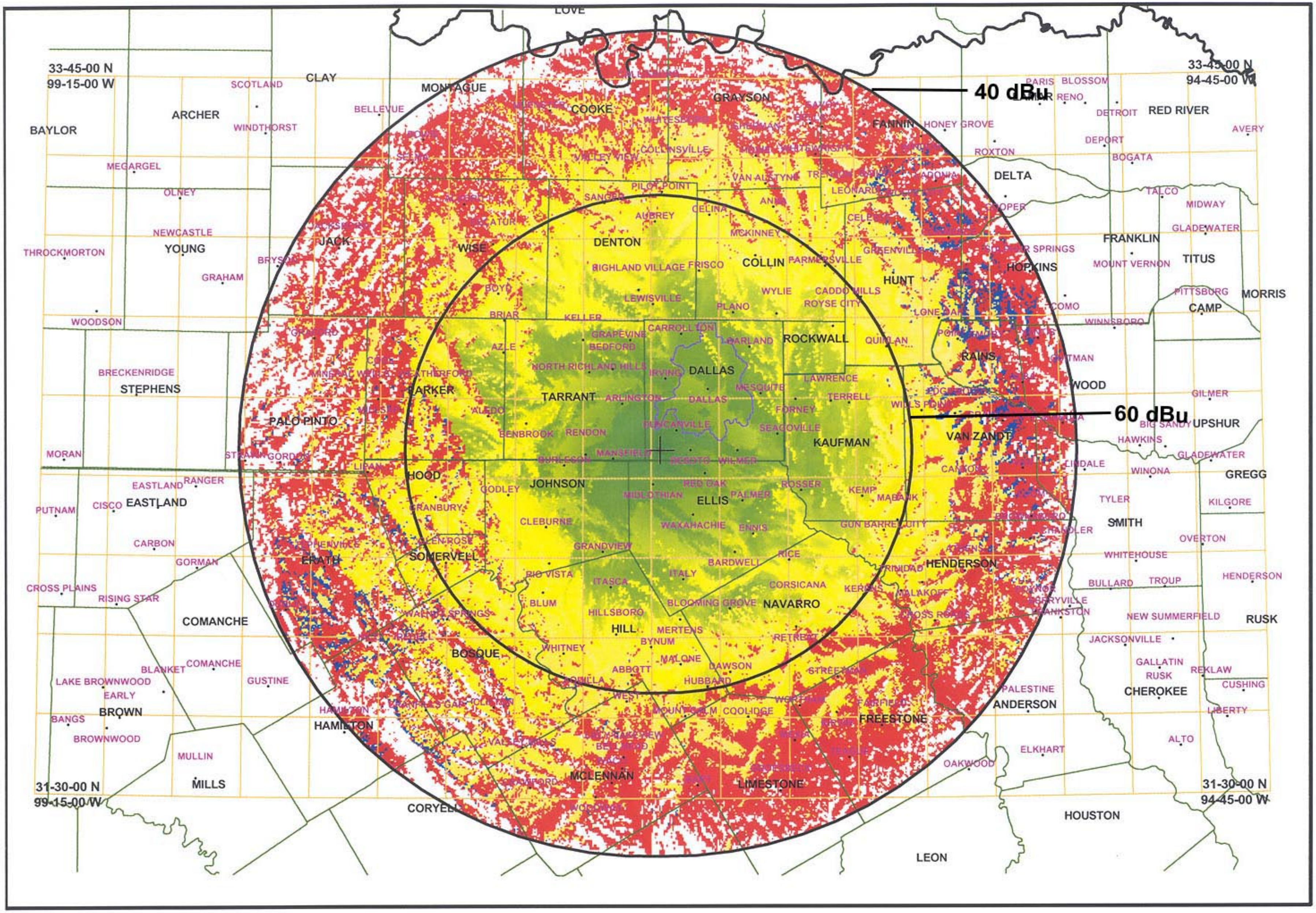
Prepared for NAB

Prepared by TechWare, Inc. Chantilly, VA 703-222-5842

0 KM 100

140.87 dBu 100.435 dBu 60 dBu

Predicted Longley-Rice Field



KEGL FORT WORTH TX Analog FM Channel 246

Interference: Analog = RED Digital = BLUE

Within and Beyond FCC Protected Contour to FCC Predicted 40 dBu

Prepared for NAB

Prepared by TechWare, Inc. Chantilly, VA 703-222-5842

0 KM 100

141.23 dBu 90.615 dBu 40 dBu

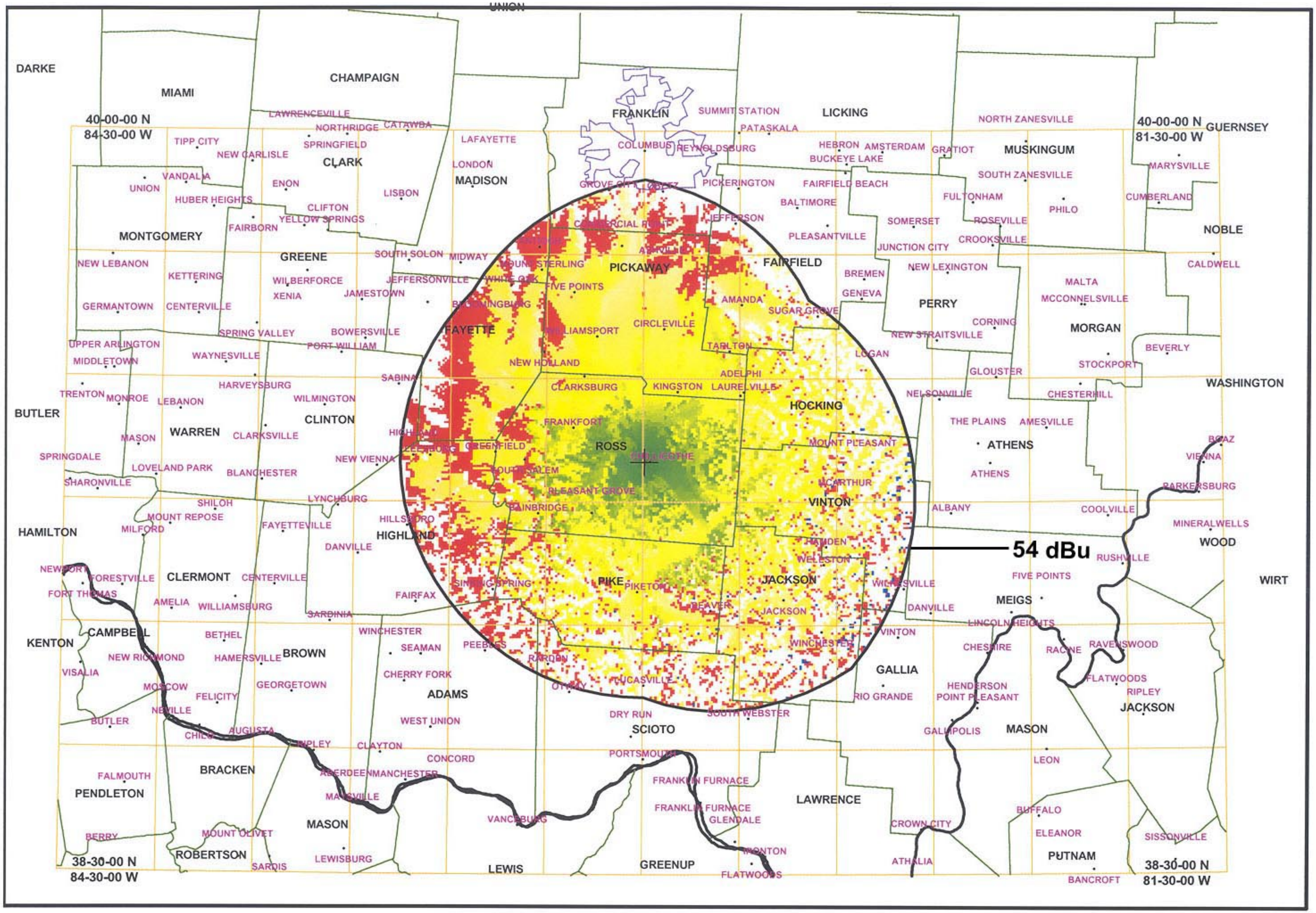
Predicted Longley-Rice Field

WKKJ CHILLICOTHE, OH CH 227B
Site location 39 19 52 82 59 49
Power 50.00000
RCAMSL 343.000
Antenna Rotation 0.0 Antenna ID 0
FCC Predicted contour 54 dBu
Station type Analog

	Within FCC Protected Contour (54 dBu)					
	Population	Area (Sq km)	Percent Change From Terrain Limited Population	Percent Change From Terrain Limited Area	Differential In Percent Change For Population IBOC-OFF/IBOC-ON	Differential In Percent Change For Area IBOC-OFF/IBOC-ON
Within FCC Predicted Contour	341,902	10,292.70				
Within Terrain Limited (Longley-Rice)	268,725	8,331.98	0.00	0.00		
Interference limited service without IBOC	220,096	6,730.06	-18.10	-19.23		
Interference limited service with IBOC	219,769	6,695.40	-18.22	-19.64	-0.12	-0.42

WKKJ CHILLICOTHE, OH CH 227B
Site location 39 19 52 82 59 49
Power 50.00000
RCAMSL 343.000
Antenna Rotation 0.0 Antenna ID 0
FCC predicted contour 40 dBu
Station type Analog

	Within and Beyond FCC Protected Contour to FCC Predicted 40 dBu Contour					
	Population	Area (Sq km)	Percent Change From Terrain Limited Population	Percent Change From Terrain Limited Area	Differential In Percent Change For Population IBOC-OFF/IBOC-ON	Differential In Percent Change For Area IBOC-OFF/IBOC-ON
Within FCC Predicted Contour	1,781,718	25,718.42				
Within Terrain Limited (Longley-Rice)	1,613,749	20,836.41	0.00	0.00		
Interference limited service without IBOC	425,323	8,513.79	-73.64	-59.14		
Interference limited service with IBOC	421,427	8,269.89	-73.89	-60.31	-0.24	-1.17



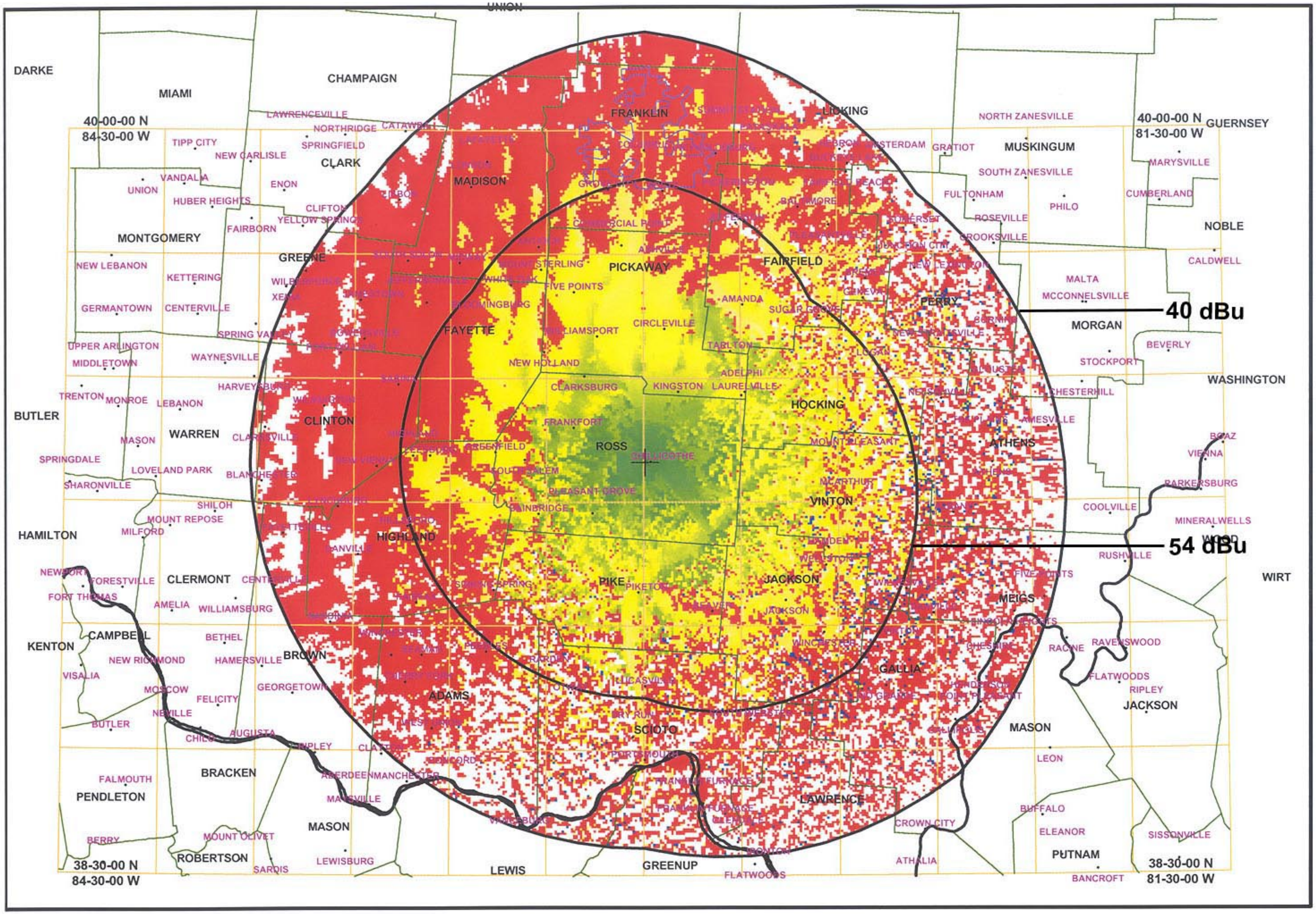
WKKJ CHILLICOTHE OH Analog FM Channel 227
Interference: Analog = RED Digital = BLUE

Within FCC Protected Contour (54 dBu)

Prepared for NAB
Prepared by TechWare, Inc. Chantilly, VA 703-222-5842

0 KM 100

138.88 dBu 96.44 dBu 54 dBu
Predicted Longley-Rice Field



WKKJ CHILLICOTHE OH Analog FM Channel 227
Interference: Analog = RED Digital = BLUE

0 KM 100

Within and Beyond FCC Protected Contour to FCC Predicted 40 dBu

140.04 dBu 90.02 dBu 40 dBu
Predicted Longley-Rice Field

Prepared for NAB
Prepared by TechWare, Inc. Chantilly, VA 703-222-5842

KFRR WOODLAKE, CA CH 281B
Site location 36 38 12 118 56 34
Power 17.00000
RCAMSL 1590.000
Antenna Rotation 0.0 Antenna ID 0
FCC Predicted contour 54 dBu
Station type Analog

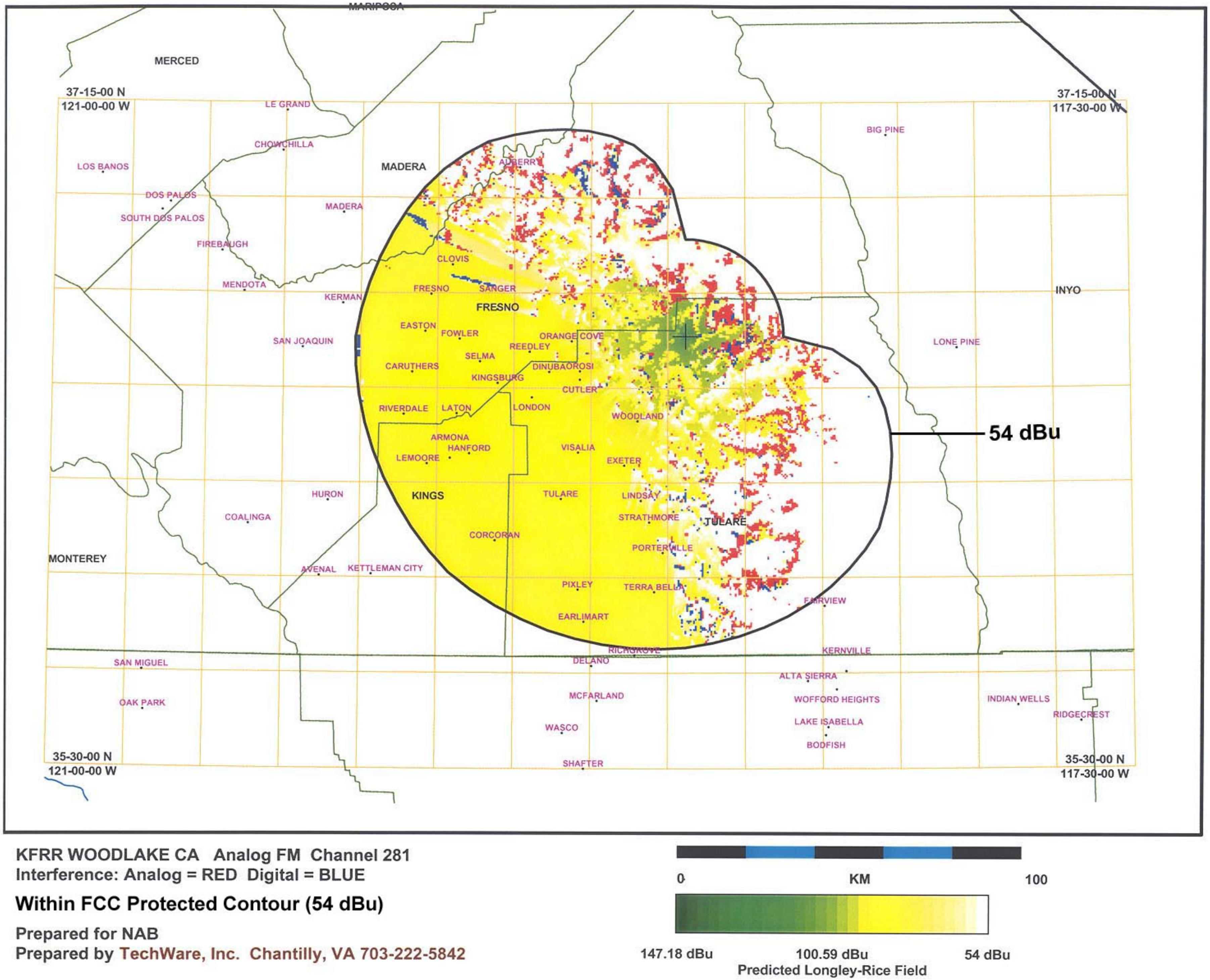
Within FCC Protected Contour (54 dBu)

	Population	Area (Sq km)	Percent Change From Terrain Limited Population	Percent Change From Terrain Limited Area	Differential In Percent Change For Population IBOC-OFF/IBOC-ON	Differential In Percent Change For Area IBOC-OFF/IBOC-ON
Within FCC Predicted Contour	1,016,230	16,973.05				
Within Terrain Limited (Longley-Rice)	1,003,587	12,362.63	0.00	0.00		
Interference limited service without IBOC	1,000,996	11,309.65	-0.26	-8.52		
Interference limited service with IBOC	997,129	11,099.00	-0.64	-10.22	-0.39	-1.70

KFRR WOODLAKE, CA CH 281B
Site location 36 38 12 118 56 34
Power 17.00000
RCAMSL 1590.000
Antenna Rotation 0.0 Antenna ID 0
FCC predicted contour 40 dBu
Station type Analog

Within and Beyond FCC Protected Contour to FCC Predicted 40 dBu Contour

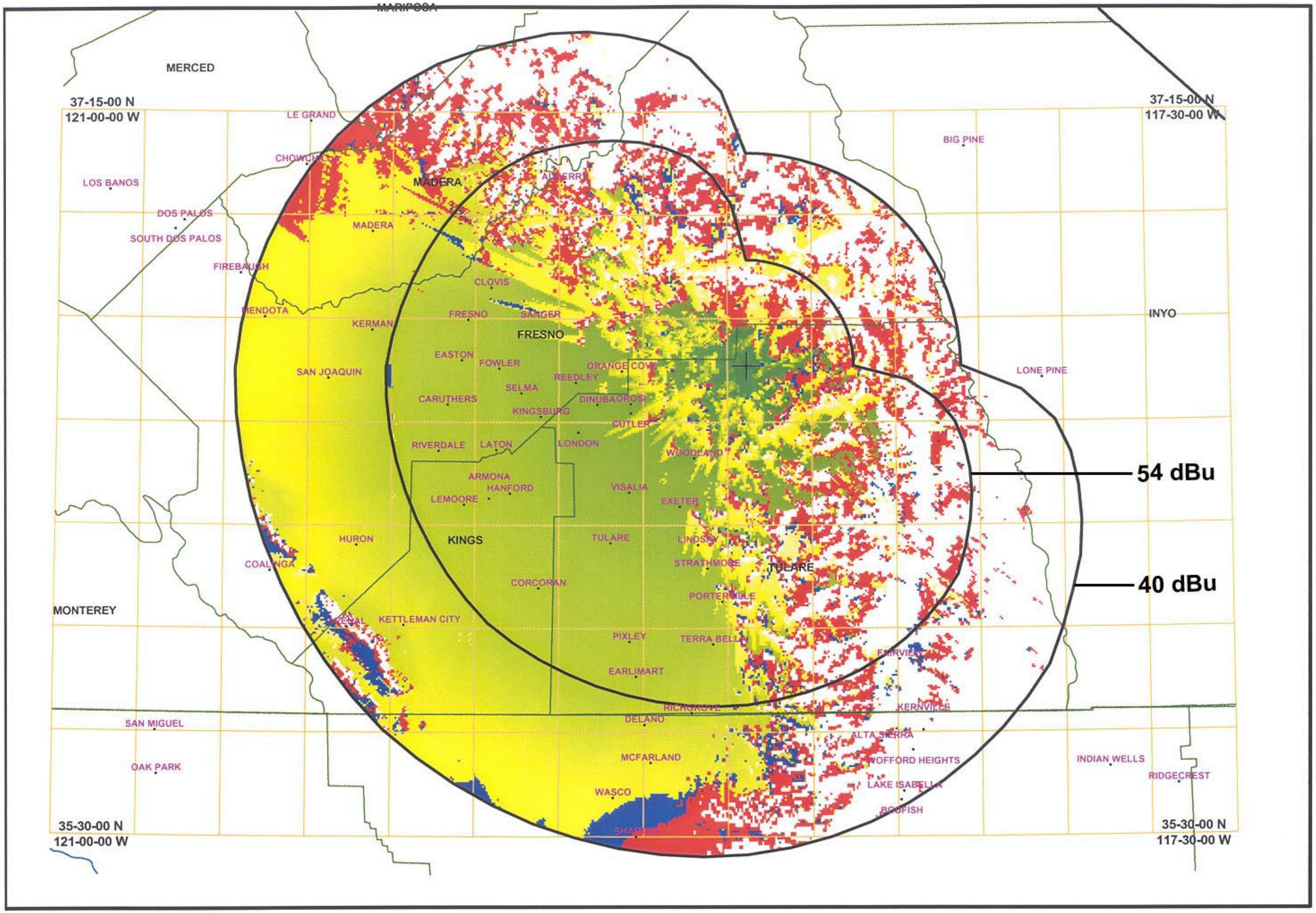
	Population	Area (Sq km)	Percent Change From Terrain Limited Population	Percent Change From Terrain Limited Area	Differential In Percent Change For Population IBOC-OFF/IBOC-ON	Differential In Percent Change For Area IBOC-OFF/IBOC-ON
Within FCC Predicted Contour	1,218,879	36,546.96				
Within Terrain Limited (Longley-Rice)	1,186,096	27,116.75	0.00	0.00		
Interference limited service without IBOC	1,152,572	21,894.95	-2.83	-19.26		
Interference limited service with IBOC	1,145,032	20,923.03	-3.46	-22.84	-0.64	-3.58



KFRR WOODLAKE CA Analog FM Channel 281
Interference: Analog = RED Digital = BLUE

Within FCC Protected Contour (54 dBu)

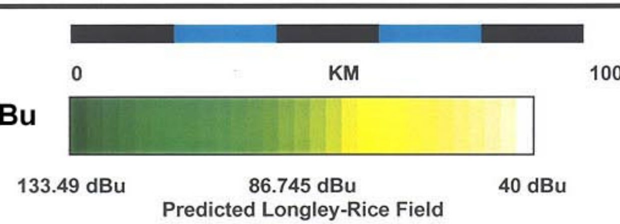
Prepared for NAB
Prepared by TechWare, Inc. Chantilly, VA 703-222-5842



KFRR WOODLAKE CA Analog FM Channel 281
Interference: Analog = RED Digital = BLUE

Within and Beyond FCC Protected Contour to FCC Predicted 40 dBu

Prepared for NAB
Prepared by TechWare, Inc. Chantilly, VA 703-222-5842



WDCZ-FM WEBSTER, NY CH 274A
Site location 43 10 14 77 40 23
Power 6.00000
RCAMSL 241.000
Antenna Rotation 0.0 Antenna ID 14894
FCC Predicted contour 60 dBu
Station type Analog

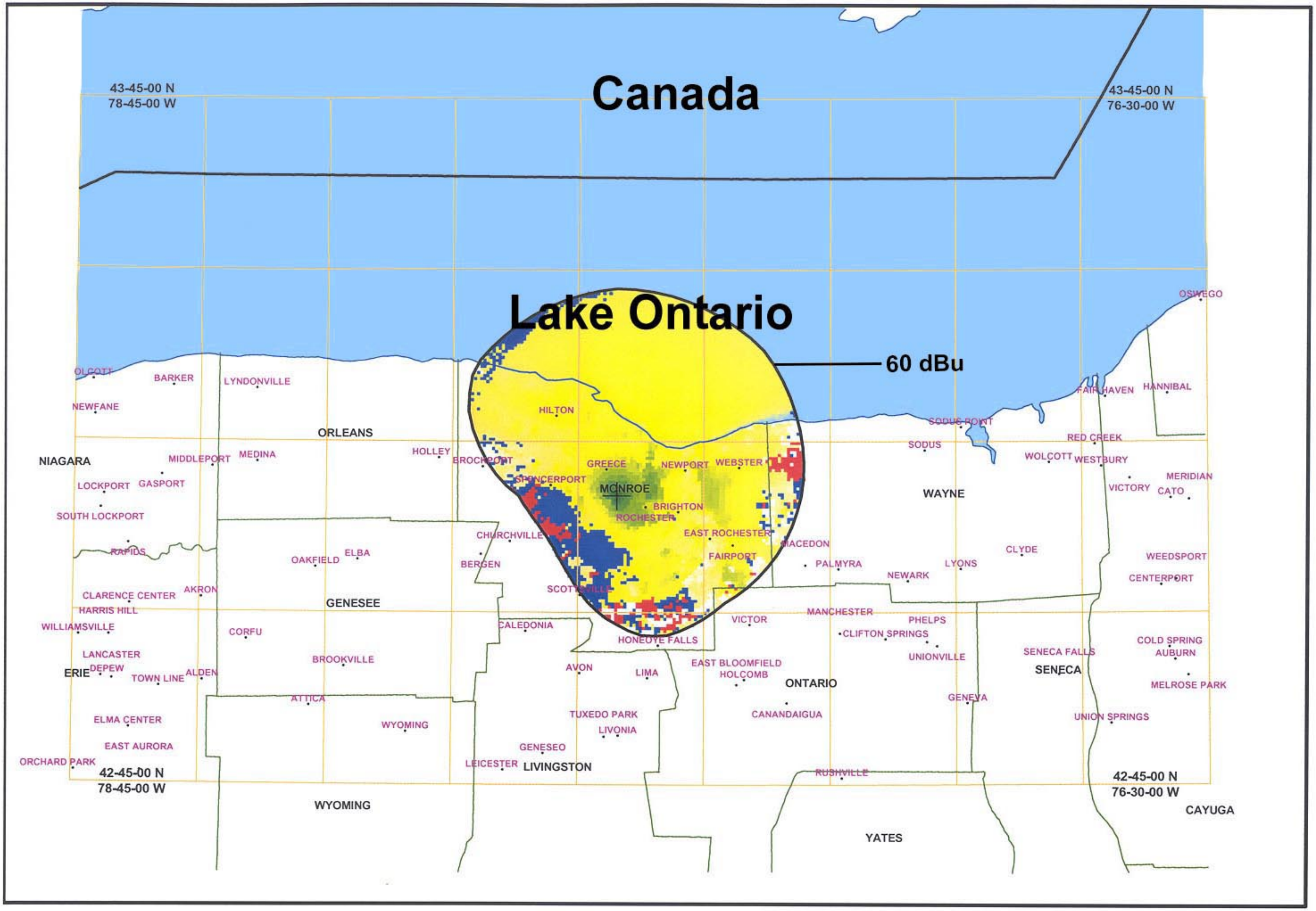
Within FCC Protected Contour (60 dBu)

	Population	Area (Sq km)	Percent Change From Terrain Limited Population	Percent Change From Terrain Limited Area	Differential In Percent Change For Population IBOC-OFF/IBOC-ON	Differential In Percent Change For Area IBOC-OFF/IBOC-ON
Within FCC Predicted Contour	691,012	2,183.63				
Within Terrain Limited (Longley-Rice)	686,996	2,127.63	0.00	0.00		
Interference limited service without IBOC	675,317	2,060.39	-1.70	-3.16		
Interference limited service with IBOC	642,035	1,854.25	-6.54	-12.85	-4.84	-9.69

WDCZ-FM WEBSTER, NY CH 274A
Site location 43 10 14 77 40 23
Power 6.00000
RCAMSL 241.000
Antenna Rotation 0.0 Antenna ID 14894
FCC predicted contour 40 dBu
Station type Analog

Within and Beyond FCC Protected Contour to FCC Predicted 40 dBu Contour

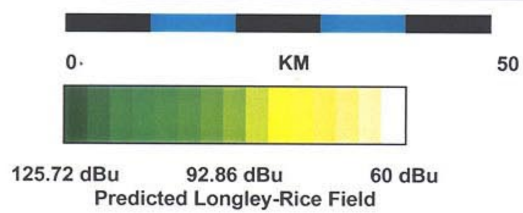
	Population	Area (Sq km)	Percent Change From Terrain Limited Population	Percent Change From Terrain Limited Area	Differential In Percent Change For Population IBOC-OFF/IBOC-ON	Differential In Percent Change For Area IBOC-OFF/IBOC-ON
Within FCC Predicted Contour	960,204	12,683.90				
Within Terrain Limited (Longley-Rice)	924,205	11,583.61	0.00	0.00		
Interference limited service without IBOC	756,200	5,743.90	-18.18	-50.41		
Interference limited service with IBOC	669,778	3,567.76	-27.53	-69.20	-9.35	-18.79

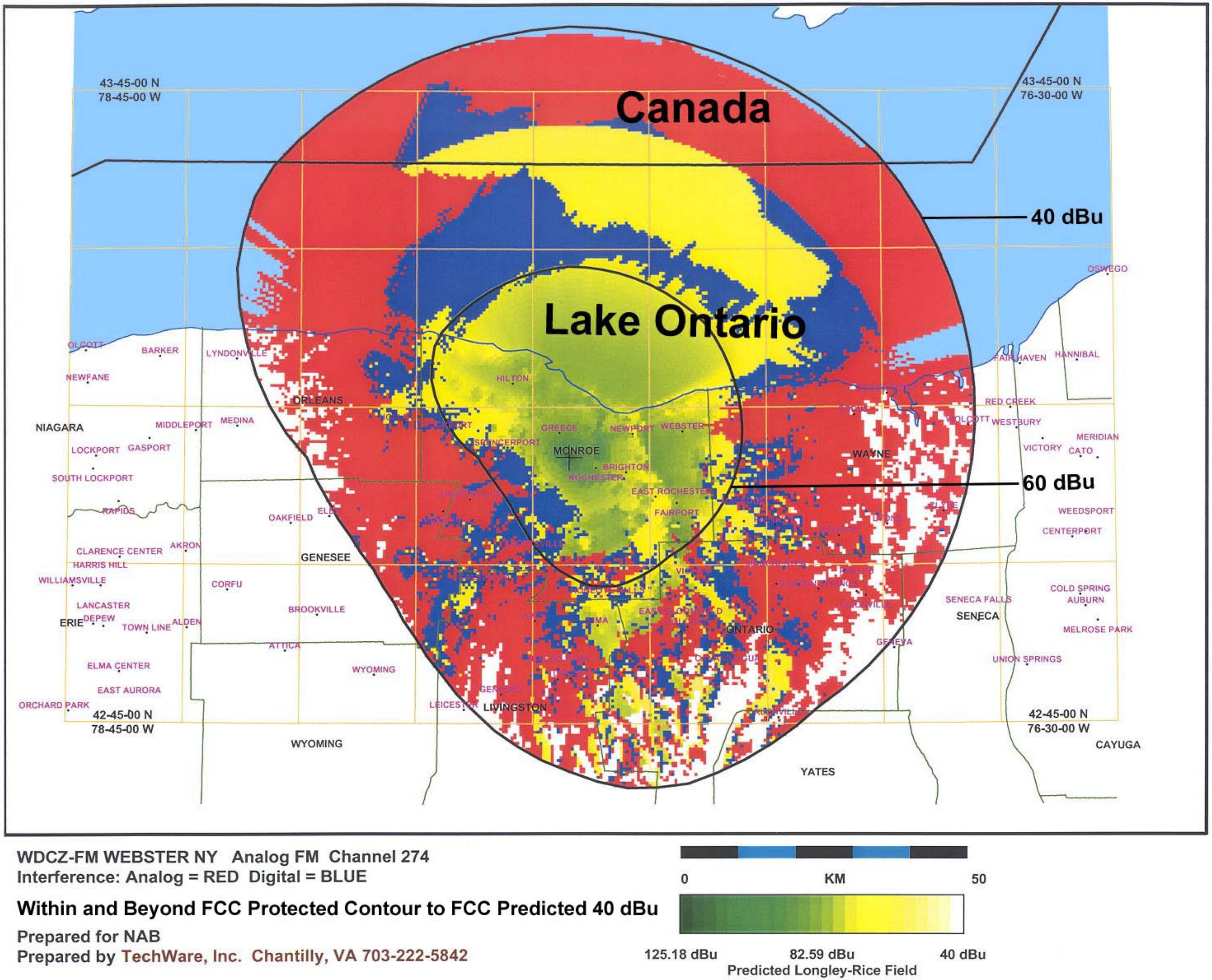


WDCZ-FM WEBSTER NY   Analog FM Channel 274
Interference: Analog = RED Digital = BLUE

Within FCC Protected Contour (60 dBu)

Prepared for NAB
Prepared by TechWare, Inc. Chantilly, VA 703-222-5842





WDCZ-FM WEBSTER NY Analog FM Channel 274
Interference: Analog = RED Digital = BLUE

Within and Beyond FCC Protected Contour to FCC Predicted 40 dBu

Prepared for NAB
Prepared by TechWare, Inc. Chantilly, VA 703-222-5842

KZFO MADERA, CA 221B1
Site location 36 57 58 120 02 06
Power 25.00000
RCAMSL 179.000
Antenna Rotation 0.0 Antenna ID 0
FCC Predicted contour 57 dBu
Station type Analog

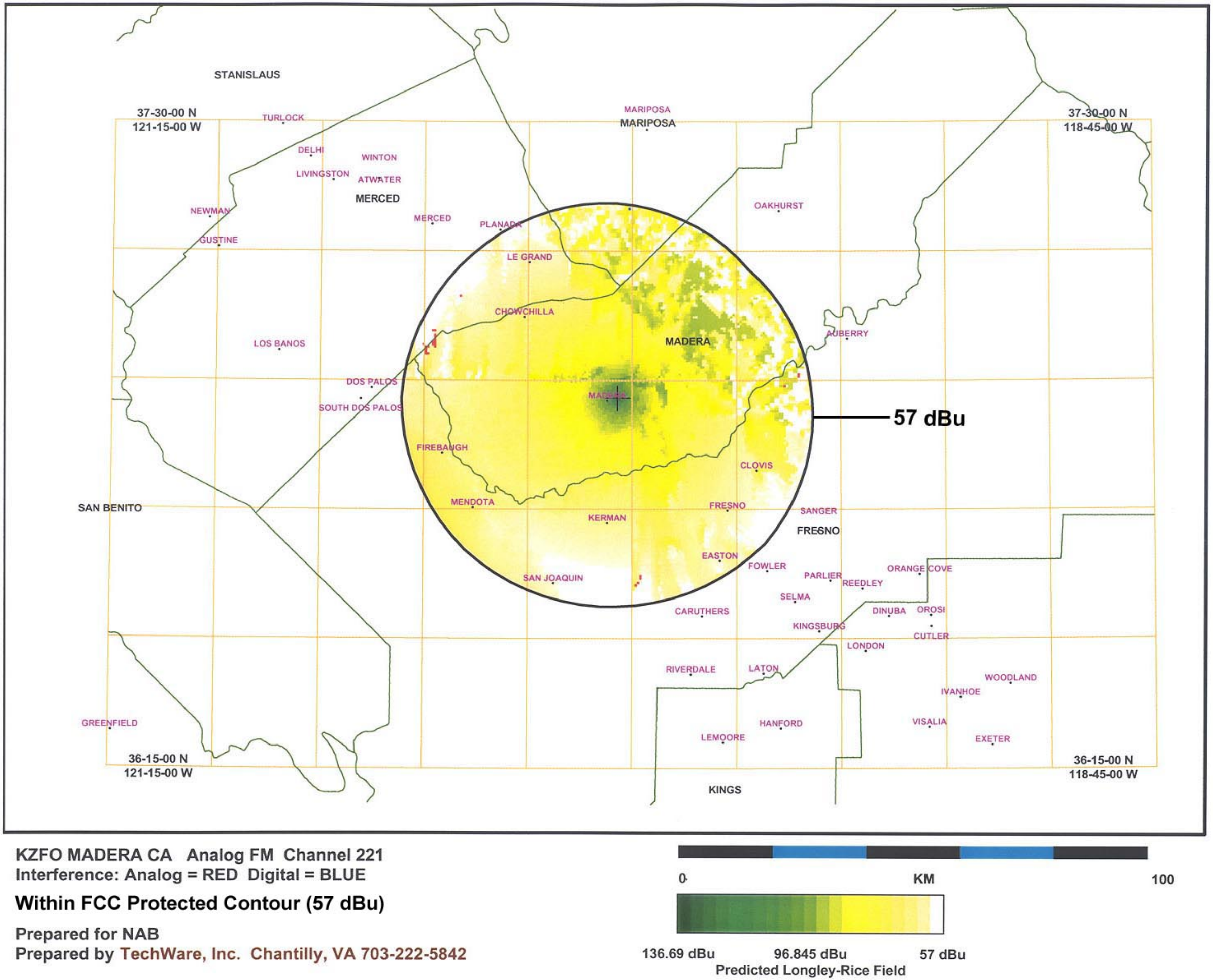
Within FCC Protected Contour (57 dBu)

	Population	Area (Sq km)	Percent Change From Terrain Limited Population	Percent Change From Terrain Limited Area	Differential In Percent Change For Population IBOC-OFF/IBOC-ON	Differential In Percent Change For Area IBOC-OFF/IBOC-ON
Within FCC Predicted Contour	589,412	5,952.21				
Within Terrain Limited (Longley-Rice)	564,746	5,338.39	0.00	0.00		
Interference limited service without IBOC	564,746	5,332.05	0.00	-0.12		
Interference limited service with IBOC	564,746	5,331.56	0.00	-0.13	0.00	-0.01

KZFO MADERA, CA 221B1
Site location 36 57 58 120 02 06
Power 25.00000
RCAMSL 179.000
Antenna Rotation 0.0 Antenna ID 0
FCC predicted contour 40 dBu
Station type Analog

Within and Beyond FCC Protected Contour to FCC Predicted 40 dBu Contour

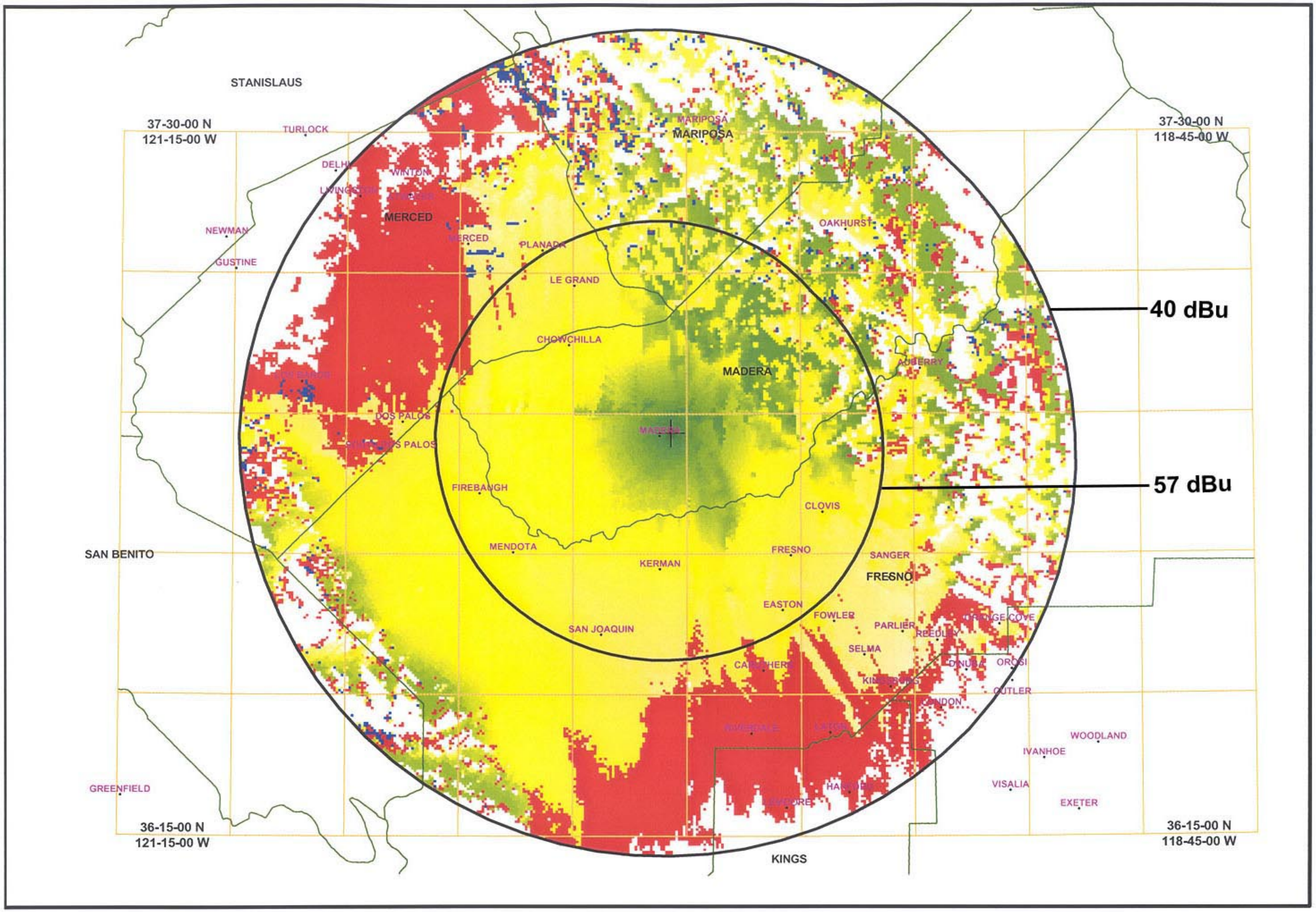
	Population	Area (Sq km)	Percent Change From Terrain Limited Population	Percent Change From Terrain Limited Area	Differential In Percent Change For Population IBOC-OFF/IBOC-ON	Differential In Percent Change For Area IBOC-OFF/IBOC-ON
Within FCC Predicted Contour	1,009,320	20,964.94				
Within Terrain Limited (Longley-Rice)	945,263	17,668.53	0.00	0.00		
Interference limited service without IBOC	777,187	13,393.83	-17.78	-24.19		
Interference limited service with IBOC	770,766	13,163.94	-18.46	-25.49	-0.68	-1.30



KZFO MADERA CA   Analog FM   Channel 221
Interference: Analog = RED   Digital = BLUE

Within FCC Protected Contour (57 dBu)

Prepared for NAB
Prepared by TechWare, Inc. Chantilly, VA 703-222-5842



KZFO MADERA CA Analog FM Channel 221

Interference: Analog = RED Digital = BLUE

Within and Beyond FCC Protected Contour to FCC Predicted 40 dBu

Prepared for NAB

Prepared by TechWare, Inc. Chantilly, VA 703-222-5842

0 KM 100

131.61 dBu 85.805 dBu 40 dBu

Predicted Longley-Rice Field

Appendix J –
FM IBOC Compatibility with Reception of Subcarrier Services

NATIONAL
RADIO
SYSTEMS
COMMITTEE

DAB Subcommittee
Evaluation of the iBiquity Digital Corporation IBOC System

Part 1 – FM IBOC

Introduction

As part of a thorough evaluation of FM IBOC, the TPWG prepared a test procedure with which the Subcommittee could attempt to determine the impact of FM IBOC on FM subcarrier services. After completing tests under this test plan, iBiquity submitted a report entitled "SCA Compatibility of the iBiquity Digital IBOC System in the FM Band." The report contains data on lab tests conducted by ATTC and the field tests conducted by iBiquity, for which all subjective testing was performed by Dynastat. Both the laboratory and field tests of subcarrier compatibility were monitored by NRSC representatives.

Summary of Findings

Host Compatibility with Analog Subcarrier Receivers

While objectively measured analog subcarrier reception can get noisier with FM IBOC signals present, and while the increased noise is often perceptible, the perceptual scores indicate that overall utility of the subcarrier is not particularly diminished with the addition of FM IBOC signals. As distance to the desired station is increased, the relative impact of the FM IBOC signal on subcarrier reception should decrease.

First Adjacent Channel Compatibility

The effect of first adjacent interference without FM IBOC signals present appears to be the controlling factor in subcarrier reception. The addition of FM IBOC signals to the first adjacent signal did not affect subcarrier reception at the desired-to-undesired ratios tested.

Second Adjacent Channel Compatibility

In general, subcarrier receivers are susceptible to all second adjacent FM signals at moderate interferer levels. As subcarrier receivers progress toward failure with increasing second adjacent analog-only signal levels, their failure is accelerated by the addition of FM IBOC on second adjacencies.

RBDS Subcarrier Reception Compatibility

There is no indication of any incompatibility between FM IBOC signals and the reception of RBDS. Reception of the RBDS data subcarrier at moderate signal levels is unaffected by the addition of FM IBOC signals to the host or to first or second adjacent signals.

DARC Subcarrier Reception Compatibility

FM IBOC signals are compatible with reception of DARC subcarrier data. Reception of the DARC data subcarrier at moderate signal levels is unaffected by the addition of FM IBOC signals to the host or to first or second adjacent signals.

Background on Subcarriers

FM subcarriers are signals that contain information and are "piggy-backed" onto FM signals. This "piggy-backing" is called "multiplexing," and involves combining the station's main channel audio, any additional stereo information signals, and one or more subcarriers prior to transmitting the radio signal. A typical analog receiver is able to recover the audio of the main channel program without appreciable degradation caused by the presence of any subcarriers. Special receivers are utilized to recover the information on a station's subcarrier. Popular uses of analog subcarriers include subscription (background) music services and free specialty audio programming targeting ethnic constituencies or providing reading services intended for persons who are print impaired. Digital subcarriers are utilized to deliver proprietary data for data subscription services, electrical load management, internal station communication and control, and the like.

With the advent of Radio Broadcast Data System (RBDS) in the USA (after 1993), some stations began sending station-related data to consumers listening to the stations' broadcasts. RBDS consists of a specialized slow-speed data subcarrier that delivers text based information and control symbols. Only those consumers who own an RBDS-enabled receiver can benefit from the additional features. This data can include a variety of information, but is largely utilized for presentation of station identifiers and music title and artist information.

Subcarrier Reception Testing

The NRSC test plan incorporated both laboratory and field testing to evaluate potential impact on subcarrier reception. Common subcarrier types were employed in the testing-- two analog audio services and two digital services. The analog subcarriers were operated on the traditional 67 and 92 kHz baseband frequencies. The digital services tested were an RBDS subcarrier (at two injection levels) and a DARC data subcarrier, employed by commercial data service providers.

Analog Subcarrier Receiver Testing

Receivers employed in the analog test were chosen to represent a range of common receivers and manufacturers. The manufacturers represented were McMartin, ComPol, CozmoCom, and Norver. Each of these companies manufacture(d) a variety of receiver models. Two of these manufacturers no longer exist but represent a large installed base of subcarrier receivers. With the assistance of the International Association of Audio Information Services, four representative receivers were selected and provided for testing. Two were operated on the 67 kHz subcarrier and two on the 92.

The analog subcarrier receiver test was determined to be an efficient way to obtain basic information on whether subcarrier users may receive perceptible interference under conditions that may be expected to challenge subcarrier receivers. Due to the nature of analog audio subcarrier reception, this sampling of receivers is not intended to provide a definitive scientific and statistically rigorous analysis of analog subcarrier reception and compatibility. The test, then, can be employed by people familiar with subcarrier performance to make reasonable inferences about the potential effects of adding FM IBOC signals to the FM spectrum.

Host FM IBOC Compatibility with Analog Subcarrier Reception

Objective Test Data

The subcarrier receivers demonstrated a wide variability in their behavior under the lab test conditions. Not only was there varying response to the presence of FM IBOC signals on the host station, but also there was varying response to changes in signal level from strong to moderate, without the presence of the FM IBOC signals (Table 1).

These measurements demonstrate that there is considerable variation in subcarrier receiver performance within the expected protected contour of a radio station. When subcarriers are transmitted on analog-only FM signals and are received under realistic noise conditions with injected AWGN, the quality of analog subcarrier reception is dependent on the received signal strength and the receiver. When signal strength is reduced from strong to moderate levels there are measurable increases in the noise reception of the tested FM subcarrier receivers.

The addition of FM IBOC signals on the host station presents challenges to subcarrier receivers similar in magnitude to the challenges presented by typical environmental radio frequency noise, as seen by comparing the summary data in Table 1 and Table 2 below.1 For reference, Table 3 contains a summary of the subcarrier same receiver tests as in Table 2, but conducted without injected radio frequency background noise.

The lab test data, as noted in the tables below, make it clear that the addition of FM IBOC signals to a station that operates an analog subcarrier will reduce the signal-to-noise performance of the received subcarrier when signal levels are strong to moderate. Hence, the greatest relative impact of FM IBOC on host subcarrier reception will be where the signal is strongest and cleanest. This information also reinforces the finding that with declining signal strength, noise increases, and the relative effects of the FM IBOC on analog subcarrier reception diminish. Because of the masking effect of reception noise outside the station's protected contour, the addition of FM IBOC signals to the desired host will have the least relative impact on subcarrier reception when the receiver is outside a station's protected contour.

[1] The data in these tables is obtained from Tables 11-14 in the laboratory test report, SCA Appendix A of iBiquity's SCA Compatibility report, pages 40 and 41.

Table 1
Lab test: Host: Without hybrid FM IBOC—
Change In Subcarrier Audio Signal-To-Noise
With Change From Strong To Moderate Received Signal Level

	Without Injected AWGN		**With Injected AWGN[2]**	
Subcarrier Receiver	**Audio Signal-to-Noise (S/N) with Strong Signal**	**Change in Audio S/N With Change to Moderate Signal Level**	**Audio Signal-to-Noise (dB WQP) with Strong Signal**	**Change in Audio S/N With Change to Moderate Signal Level**
McMartin 67 kHz	36.5 dB WQP	+1 dB*	36.2 dB WQP	-5 dB
Norver 67 kHz	31.7	0	31.2	-6
CozmoCom 92 kHz	28.9	0	28.8	-1
ComPol 92 kHz	27.9	0	27.0	-9

*A positive figure in the highlighted "Change" columns represents improvement in noise performance at the moderate signal strength with respect to the strong signal strength. A negative figure represents deterioration in noise performance at the moderate signal strength.

Table 2
Lab Test: Host: Injected RF background noise (AWGN)--
Change In Subcarrier Audio Signal-To-Noise Level
With The Addition of FM IBOC Signals

With Injected AWGN	Desired At Strong Signal Level		Desired At Moderate Signal Level	
Subcarrier Receiver	**Audio S/N without IBOC**	**Change in Audio S/N with FM IBOC Added**	**Audio S/N without FM IBOC**	**Change in Audio S/N with FM IBOC Added**
McMartin 67 kHz	36.2 dB WQP	-6 dB	31.2 dB WQP	-3 dB
Norver 67 kHz	31.2	-12	24.8	-6
CozmoCom 92 kHz	28.8	-7	27.4	-6
ComPol 92 kHz	27.0	-19	18.5	-10

[2] The injection of 30,000 K noise into the test bed has been determined by the Committee to be a realistic simulation of actual reception conditions. In contrast, the use of a test bed with no injected noise presents the test receivers with unrealistically pristine RF conditions. Such conditions fail to adequately represent typical background energy to which receivers are subjected in the field. However, tests without injected background noise are valuable tools for qualifying results of injected noise tests and for isolating other variables in tests to view their particular effects for diagnostic purposes. This subcarrier report refers to tests with AWGN injected unless otherwise indicated.

Table 3
**Lab Test: Host: No Injected RF background noise (AWGN)--
Change In Subcarrier Audio Signal-To-Noise Level
With The Addition of FM IBOC Signals**

Without Injected AWGN	Desired At Strong Signal Level		Desired At Moderate Signal Level	
Subcarrier Receiver	**Audio S/N without IBOC**	**Change in Audio S/N with FM IBOC Added**	**Audio S/N without FM IBOC**	**Change in Audio S/N with FM IBOC Added**
McMartin 67 kHz	36.5 dB WQP	-7 dB	37.6 dB WQP	-8 dB
Norver 67 kHz	31.7	-12	31.3	-12
CozmoCom 92 kHz	28.9	-7	29.3	-7
ComPol 92 kHz	27.9	-19	27.9	-17

Because field conditions on the whole have been determined to be best reflected in the lab by the presence of AWGN on the test bed3, the results with AWGN in the subcarrier testing deserve the closer scrutiny. Throughout this subcarrier report, the lab tests with injected AWGN are utilized unless otherwise indicated.

Subjective Test Data

While the lab test data illustrate the numerical change in signal to noise performance of a received analog subcarrier on a small sample of receivers, the data cannot indicate the perceived significance of a change in noise performance. To evaluate the perceived impact of host FM IBOC signal effects on reception of the host station's analog subcarriers, subjective testing was conducted with recordings from both lab and field tests.

Male and female voice selections were recorded on both the lab and field subcarrier tests. Musical selections were recorded on the lab tests, but not employed in the subjective analysis. The vocal selections are most representative of the content broadcast on reading services. Vocal content is also likely to be the most challenging under interference conditions because a single voice is not aurally dense enough to continuously mask noise, whereas processed music often is.

iBiquity submitted a table, "Lab Compatibility, SCA Host," (page 1 of its SCA Appendix C) that presents the average subjective MOS scores4 for each subcarrier receiver, with and without the FM IBOC signal

[3] See the NRSC FM IBOC Evaluation Report, section 4.2 for further discussion on the Committee's findings regarding the use of injected AWGN in laboratory tests. It has been the experience of the EWG in main channel tests that the use of injected AWGN in the lab best corresponds with field results.

[4] The Absolute Category Rating Mean Opinion Scores (ACR-MOS) are averages of integer scores given by test listeners using a scale in which 5, 4, 3, 2, and 1 represent Excellent, Good, Fair, Poor, and Bad, respectively. The subcarrier tests utilized the same "anchor" points of reference for quality as the main channel audio tests. Since subcarrier audio is inherently lower in quality than good main channel audio, subcarrier scores are less likely to score high, giving them less resolution on the remainder of the ACR scale.

activated. The table separates male and female audio cuts (and averages them with little change in result). It also separates tests with and without AWGN inserted under the test signal.

AWGN in Subjective Tests

On first blush, the inclusion of AWGN does not affect the MOS score of the CozmoCom receiver. Its male/female total remains at 2.1 with or without AWGN (and no FM IBOC). However, the EWG observed that the CozmoCom host compatibility recordings in this lab test were compromised by the presence of main channel crosstalk. Hence, the addition of AWGN does not appear to affect the perception of the receiver performance possibly because the quality is already poor. In field tests, there was no apparent crosstalk in the CozmoCom, which was tested on WD2XAB with classical music on the main channel. It is therefore not clear whether the receiver or the lab test configuration may have been the cause of the crosstalk.

In contrast, the other three receivers, without FM IBOC signals present, were diminished in performance with the addition of AWGN. Their starting values were higher than the CozmoCom's 2.1 MOS, showing 3.6, 3.3, and 4.0 for the ComPol, McMartin, and Norver. After AWGN was added, their performance slipped to 2.6, 3.0 and 3.0 respectively—still better than the CozmoCom at its best. These average scores starting between Good and better-than-Fair, shifted to being between Fair and better-than-Poor.

This response to AWGN (at moderate and strong signal levels) demonstrates the susceptibility of subcarrier receivers to outside influences within the host station's protected contours, even without the addition of FM IBOC signals.

Subjective Tests of Host Compatibility Lab Recordings

Under AWGN conditions, the addition of FM IBOC signals in the lab yielded FM IBOC Mean Opinion Scores of 2.6/1.4, 3.0/2.9, and 3.0/2.4 (without FM IBOC/with FM IBOC) among the latter three receivers. The CozmoCom, already compromised by crosstalk, changed from 2.1 to 1.7. Among the other three receivers, the McMartin showed on the average essentially no perceptible change. The Norver showed a change that just exceeds the confidence interval, suggesting the change was perceptible in some cases. The ComPol, which audibly seemed to pass higher frequencies (including noise) more readily than the others, produced the most dramatic change in MOS score with the addition of FM IBOC signals.

Subjective Tests of Host Compatibility Field Recordings

The field tests for Host Compatibility of subcarrier reception included two radio stations, each with two subcarriers and one receiver per subcarrier, received at three locations each.

The test signals on WPOC were corrupted by main channel crosstalk that did not appear to be related to multipath reception or individual receiver performance. The Norver receiver at 67 kHz and the ComPol at 92 kHz rated 1.9 MOS or less in each location, whether or not the FM IBOC signal was activated. Data from these two tests is not considered here. However, an experienced listener may glean some understanding of FM IBOC related noise mechanisms by listening to these sound cuts with the rest. For instance, even in the presence of distracting crosstalk, the variations in background hiss that occur with variations in signal level, AWGN, and analog/FM IBOC modes, appear to be consistent with other field and lab test recordings.

The data in iBiquity's "Field Host Compatibility" table shows the McMartin and CozmoCom receivers scoring quite well, both with and without the FM IBOC signals present. At three locations the

CozmoCom receiver, on 92 kHz, scored from 3.1 to 4.4 without FM IBOC. With FM IBOC added, the scores changed to between 2.9 and 3.5. Performance that was good-to-fair diminished to fair-and-better-than-fair.

The McMartin receiver on 67 kHz ranged from 3.8 MOS to 4.5 without FM IBOC. With FM IBOC, the scores stayed within overlapping confidence intervals of the original values, ranging from 3.6 to 4.4. The McMartin showed that it received no material change in performance with the addition of FM IBOC signals to the host.

Lab and Field Test Differences

The lab and field recordings for host subcarrier compatibility differ somewhat. The lab test recordings reveal more noise on the recordings with the FM IBOC present than the field recordings do. Mean Opinion Scores reflect this disparity as well. Mean Opinion Scores remain fairly high in both cases with the addition of FM IBOC signals.

The signal strengths used in the lab represent strong reception well within a station's protected contour and moderate reception comparable to strength at the contour. The field tests of the McMartin and CozmoCom on experimental station WD2XAB ranged from 53 to 75 dBu, which are comparable to the range of strong to moderate as approximated in the lab tests. There is no clear explanation for the clear, minor differences in the lab and field recordings. It has been the experience of the committee and in particular of several of its members involved in this type of testing that field conditions, with respect to RF noise and non-interfering out of band signals, can affect the way a receiver responds to the desired signal. The use of the 30,000 K AWGN in the lab is an important factor in simulating the impact of the radio frequency energy environment in the field, but may not duplicate it entirely.

Effect of Signal Strength

Signal strengths below the moderate level utilized in the tests represent subcarrier reception typically outside a station's protected signal coverage area. The impact of host FM IBOC signals can be inferred based on the observations available. The ATTC laboratory test summary contains spectrum analyzer plots of the demodulated baseband of various signals under test.5 Assuming that the commercial demodulator used to generate the analyzer plots behaves similarly to a typical receiver, the baseband plots reveal the relationship between signal strength, injected RF noise, host FM IBOC presence, and resulting composite baseband noise. In general, as the RF noise is increased, or the signal level is decreased, the noise in the subcarrier portion of the FM baseband increases. Lower signal levels and higher RF noise levels produce a masking effect that diminishes the impact of FM IBOC signals on the demodulated baseband. Consequently, it is reasonable to infer that as a subcarrier receiver is moved further from the host station, the received baseband noise will increase, and the noise of receiving the station will meet and exceed the noise generated in the receiver with the presence of FM IBOC signals.

Host Compatibility with Analog Subcarrier Receivers Conclusion

While objectively measured analog subcarrier reception may get noisier with FM IBOC signals present, and while the increased noise is often perceptible, the perceptual scores indicate that overall utility of the subcarrier is not particularly diminished with the addition of FM IBOC signals, because the field test subjective scores remain well above the listener "tune-out" threshold of approximately 2 MOS that was

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[5] SCA Compatibility Report, Appendix A, ATTC Document #01-16B, *SCA Compatibility of the iBiquity Digital IBOC System in the FM Band*, Oct 17, 2001, pp. 23-38

identified in Appendix J of the iBiquity main report. As distance to the desired station is increased, the relative impact of the FM IBOC signal on subcarrier reception should decrease.

First Adjacent Channel Compatibility with Subcarrier Reception

Laboratory tests were conducted on each of four subcarrier receivers, two on 67 kHz and two on 92 kHz subcarriers. Interferers on lower and upper adjacencies were tested separately. To obtain objective test data, test signals were utilized that permitted consistent measurement conditions. For recording subjective test audio samples, the test signals were replaced with program audio that permitted the main channels of the signals under test to have a "beat" component that is commonly found on radio stations and commonly heard when adjacent channel interference occurs.

First Adjacent Channel Compatibility Objective Tests

The objective tests for first adjacent channel interference to subcarrier reception were performed with the desired signal 6 dB and 16 dB above the undesired signal (+6 and +16 dB D/U). The 6 dB D/U ratio is the threshold utilized in protecting stations from interference at their protected contours. The 16 dB D/U value is less challenging to receivers.

The summary of results contained in the text below is derived from the iBiquity SCA Compatibility Report, Appendix A, Tables 3-6.

The McMartin receiver did not reveal any variation in Weighted Quasi Peak (WQP) noise between tests with and without FM IBOC signals on the first adjacent channel. Pairs of measured values were within 1 dB of each other.

The Norver receiver revealed no change at +16 dB D/U, with and without FM IBOC signals on first adjacent channel. However, its overall noise figures, around 15 dB WQP, were 9 to 12 dB worse than the McMartin. At 6 dB D/U, the Norver developed noise that measured in single digits, which may qualify as unlistenable. At 6 dB D/U, the Norver registered a 2 dB variation with the addition of FM IBOC on first adjacent channel. The Norver is clearly already compromised by first adjacent analog-only signals at these D/U ratios.

The CozmoCom receiver subjective lab recordings had what may have been the same main channel crosstalk that appeared in the lab tests for host compatibility, but the noise and interference components mostly masked the crosstalk. It is not clear whether the crosstalk also might have occurred during the objective tests with the different test audio signals employed. The CozmoCom receiver varied 0.3 dB or less with the addition of FM IBOC signals on first adjacent channel, with one exception. Without AWGN injected, the +16 D/U ratio revealed a 3.9 dB degradation on lower 1st adjacent channel and a1.6 dB change on upper. Like the Norver, 16 dB D/U measurements were in the teens of dB WQP, and in single digits at +6 dB D/U. The CozmoCom is clearly already compromised by first adjacent analog-only signals at these D/U ratios.

The signal to noise ratios for first adjacent interference in the ComPol receiver were all in the single digits and addition of FM IBOC signals on first adjacent channel did not vary the results more than 0.4 dB.

Overall, first adjacent channel interference exhibited by the tested subcarrier receivers in objective testing was challenging to the receivers whether or not the first adjacency had FM IBOC activated. The test results suggest that analog subcarrier reception is susceptible to first adjacent interference within the protected contour of a desired station.

First Adjacent Channel Compatibility Subjective Tests

Subjective testing of first adjacent channel compatibility of subcarrier reception with FM IBOC signals supports the results of the objective tests. With low figures of 1.1 MOS and a single high of 2.7, the subjective tests placed first adjacent performance without FM IBOC had a median of 1.8 MOS, slightly less than Poor. With FM IBOC the range was 1.1 to 2.6 MOS, with a median also of 1.8.

First Adjacent Channel Compatibility Conclusions

The effect of first adjacent interference without FM IBOC signals present appears to be the controlling factor in subcarrier reception. When the desired signal was sufficiently stronger than the undesired signal to meet FCC interference criteria, the subcarrier receivers delivered poor performance. The addition of FM IBOC signals to the first adjacent signal did not affect subcarrier reception at the desired-to-undesired ratios tested.

Second Adjacent Channel Compatibility with Subcarrier Reception

The subcarrier receiver tests utilized desired-to-undesired signal ratios that placed the undesired second adjacent analog signal equal to and greater than the desired signal in ten dB steps (from 0 to -30 dB D/U). The -30 dB desired-to-undesired signal ratio is not as severe as the endpoint of –40 dB D/U anticipated by FCC allocation methods. However, subcarrier receivers are generally not expected to perform at –40 dB D/U, as evidenced by their measured performance at –30. The -30 dB D/U ratio was a suitably challenging ratio for the purposes of this testing.

McMartin Receiver

Below is a graph (Figure 1) of the various tests performed on the McMartin receiver with a second adjacent signal. The X-axis contains the D/U ratio in dB. The Z-axis contains the variations in test conditions, grouped in two halves, with and without AWGN noise injected into the test bed. Each group contains two pairs-- one pair without FM IBOC signals on the adjacency and one pair with. Each pair consists of the test performed on the lower adjacency and the upper adjacency. The results are presented on the Y-axis as strips of weighted quasi peak signal to noise values. The lower the value, the poorer the signal quality.

The graph readily shows that the injection of AWGN into the test signal brings down the signal to noise ratio in comparison to those without 30,000 K AWGN. The Committee has determined that the injected noise more closely approximates the actual noise environment under field conditions.

In a noiseless environment, on the test bed, the introduction of FM IBOC signals to the second adjacent signal appear to have an impact on the McMartin reception quality at D/U ratios as low as –10 dB. With the noise masking that comes from the injected AWGN, the impact of the FM IBOC signals is less apparent, until the D/U ratio becomes more severe. At the –30 dB D/U ratio, the McMartin fails to produce discernable audio with FM IBOC signals on the second adjacency.

The McMartin retains respectable noise performance better than 29 dB WQP, in all conditions, from the zero through –20 dB D/U ratios. While there is better noise performance in the absence of AWGN, reception in the field is likely to contain energy more closely approximated by the 30,000 K AWGN.

Therefore, up through –20 dB D/U ratios, the impact of the second adjacent FM IBOC signals on the McMartin is likely to be negligible.

The subjective test data on the McMartin supports the lab data by showing that at –10 dB D/U the score is always 2.5 MOS or greater with AWGN and 3.6 or greater without AWGN. All MOS scores for analog only 2nd adjacent signals were matched within one-tenth dB by their corresponding FM IBOC test samples. Subjectively, second adjacent interference to the McMartin subcarrier receiver on 67 kHz is not discernable at this D/U ratio.

At the –20 D/U ratio the McMartin objective performance remains fairly stable without FM IBOC signals present. The addition of FM IBOC signals at –20 dB D/U shows a slight degradation that may or may not be perceptible.

Extended to –30 dB D/U, the analog-only adjacent signals appear to cause a slide in performance, but not steeply. The measured test signals with FM IBOC signals drive the receiver into very noisy performance at this ratio.

The subjective data at –30 dB D/U with FM IBOC present on second adjacent show the McMartin performing badly, which is consistent with the objective data. The 3.7 dB WQP signal to noise figures of the lower 2nd adjacent test correspond to Poor-to-Bad subjective results. On the upper adjacency the 0.3 dB signal to noise figures, essentially total failure, conform to the subjective audio which was not distinguishable enough to subjectively test.

Without FM IBOC, however, the upper second adjacent subjective audio was also not distinguishable or nearly so. Contrary to this subjective condition, the objective lab data show that upper second adjacency at –30 dB D/U should make a respectable showing of little noise degradation. This inconsistency could be caused by an error in the objective data collection or by a difference between the way the objective test signals were modulated versus the subjective test signals. The subjective test recordings were conducted under actual program audio modulation conditions rather than with test signals, and therefore are more likely to be reliable indicators of the McMartin performance.

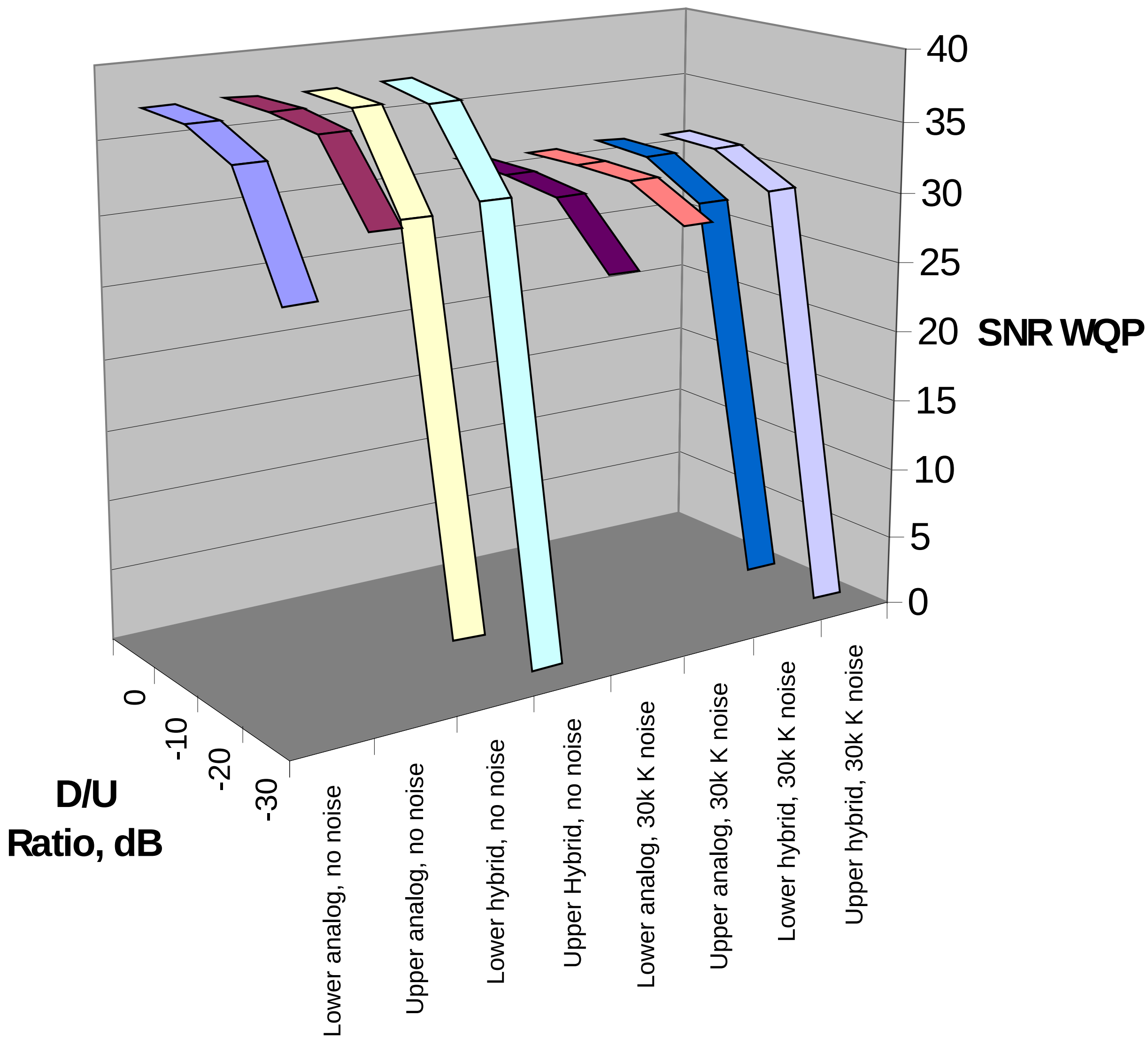
Norver Receiver

The Norver subcarrier receiver obtained poorer marks in objective testing than the McMartin. Its objective performance showed poor resistance to 2nd adjacent channel interference, regardless of the presence or absence of the FM IBOC signal. At –20 dB D/U, the Norver was already well on its way to failure without FM IBOC present. The addition of FM IBOC signals to the 2nd adjacencies accelerated the failure of the receiver, but not until it was well on its way already.

The subjective data for the Norver reinforce the objective results. At –10 dB D/U on 2nd adjacencies, the subjective scores hovered around 2.3 MOS (slightly above Poor) whether or not FM IBOC signals were present on a second adjacency. At –30 dB D/U the Norver was in failure, independent of the status of the FM IBOC signal. As with the McMartin, this, too, illustrates how the objective testing may understate the impact of the analog-only adjacency on the performance of the receiver. The Norver is simply susceptible to severe degradation in the presence of moderate to strong second adjacent analog interferers.

McMartin 2nd Adjacent Noise, 67 kHz

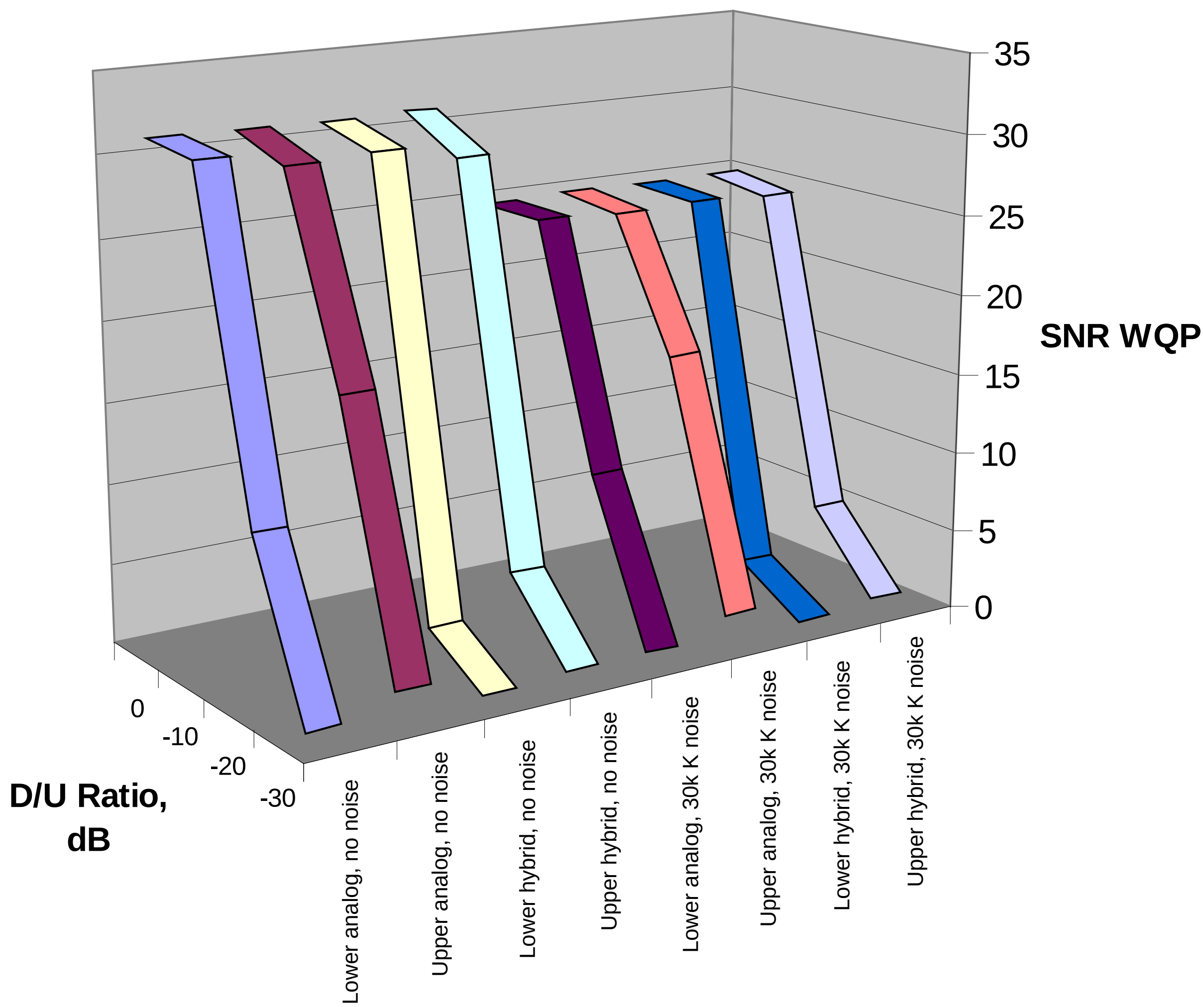
Figure 4
Data obtained from SCA Compatibility Report Appendix A, Table 3, pp. 10-11



	0	-10	-20	-30
Lower analog, no noise	37.5	37.3	35.7	28
Upper analog, no noise	37.5	37.5	37	31.8
Lower hybrid, no noise	37.4	37.2	30.7	3.7
Upper Hybrid, no noise	37.5	36.8	31.2	0.3
Lower analog, 30k K noise	31.3	31.2	30.7	26.6
Upper analog, 30k K noise	31.2	31.3	31.1	29.1
Lower hybrid, 30k K noise	31.3	31.2	28.8	3.7
Upper hybrid, 30k K noise	31.2	31.1	29	0.3

Norver 2nd Adjacent Noise, 67 kHz

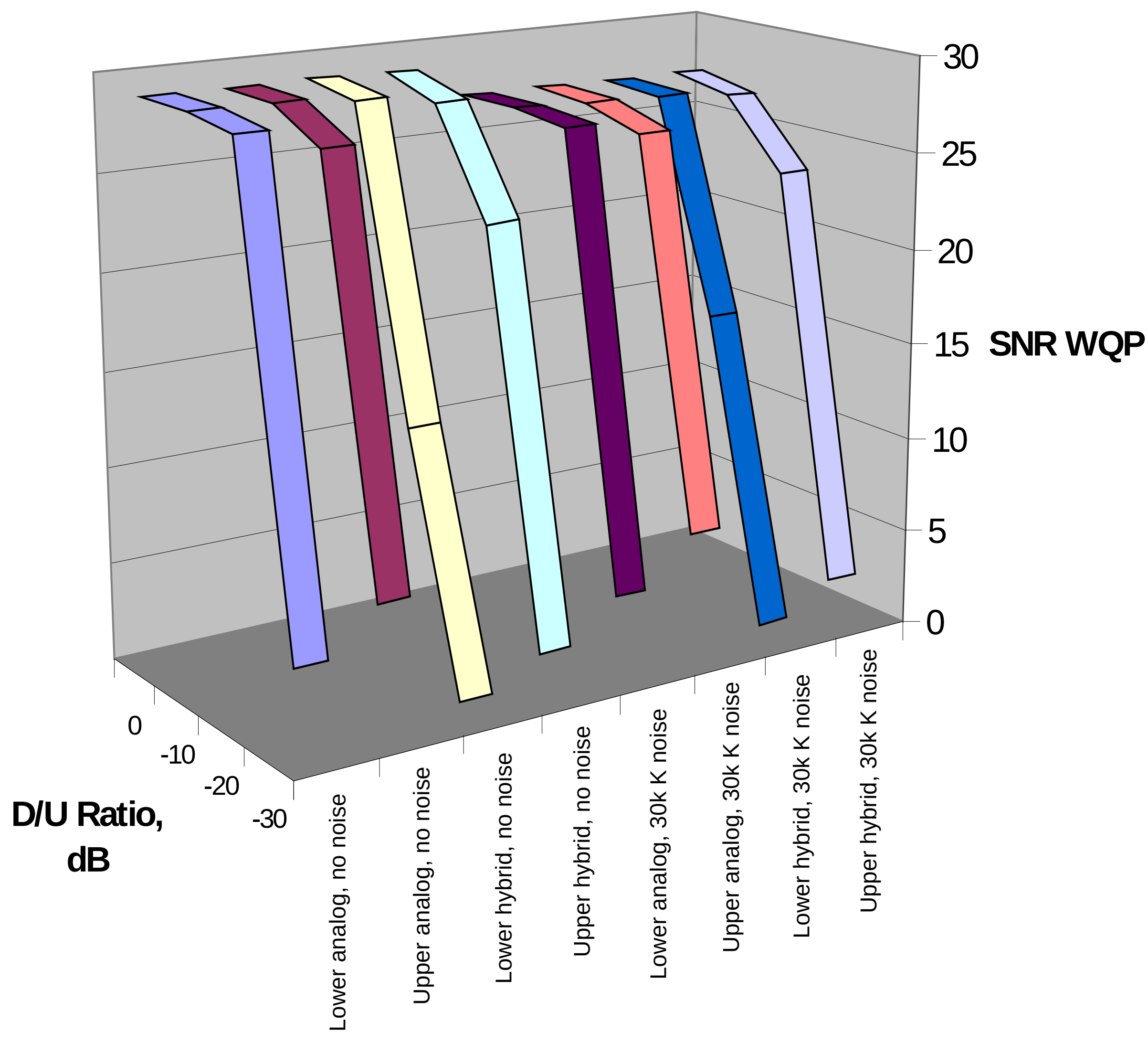
Figure 5
Data obtained from SCA Compatibility Report Appendix A, Table 4, pp. 12-13



	0	-10	-20	-30
Low er analog, no noise	31.2	30.8	10.5	0.4
Upper analog, no noise	31.2	29.9	17.6	1.6
Low er hybrid, no noise	31.1	30.1	2.6	0.1
Upper hybrid, no noise	31.2	29.2	4.9	0.4
Low er analog, 30k K noise	24.8	24.8	10	0.4
Upper analog, 30k K noise	24.9	24.5	16.6	1.6
Low er hybrid, 30k K noise	24.8	24.6	2.5	0.1
Upper hybrid, 30k K noise	24.9	24.3	5	0.5

CozmoCom 2nd Adjacent Noise, 92 kHz

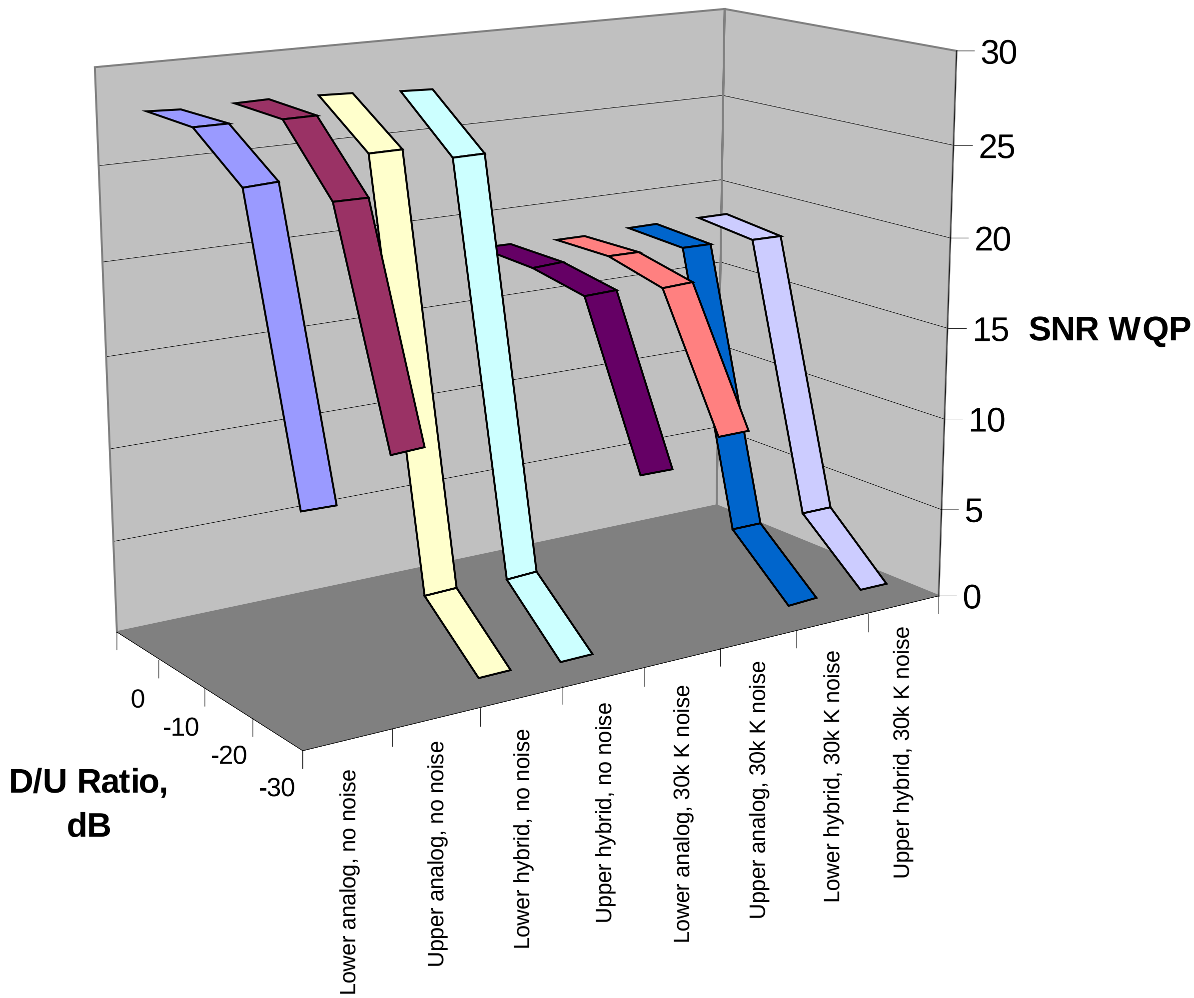
Figure 6
Data obtained from SCA Compatibility Report Appendix A, Table 5, pp. 14-15



	0	-10	-20	-30
Lower analog, no noise	29	29	28.6	4.3
Upper analog, no noise	29	28.9	27.4	6.5
Lower hybrid, no noise	29	28.6	13.2	0.6
Upper hybrid, no noise	28.9	28	22.7	2.1
Lower analog, 30k K noise	27.3	27.3	27	4.1
Upper analog, 30k K noise	27.3	27.1	26.2	6.5
Lower hybrid, 30k K noise	27.2	27	16.1	0.7
Upper hybrid, 30k K noise	27.2	26.6	23.2	2.2

ComPol 2nd Adjacent Noise, 92 kHz

Figure 7
Data obtained from SCA Compatibility Report Appendix A, Table 6, pp. 16-17



	0	-10	-20	-30
Low er analog, no noise	27.9	27.8	25.7	10.9
Upper analog, no noise	27.9	27.8	24.4	12.9
Low er hybrid, no noise	27.8	25.5	3.4	0.4
Upper hybrid, no noise	27.6	24.8	3.3	0.3
Low er analog, 30k K noise	18.5	18.4	17.8	9.3
Upper analog, 30k K noise	18.4	18.4	17.6	10.6
Low er hybrid, 30k K noise	18.5	18.2	3.3	0.4
Upper hybrid, 30k K noise	18.5	18.1	3.4	0.3

CozmoCom Receiver

The first of the two 92 kHz subcarrier receivers, the CozmoCom, was affected by second adjacent FM IBOC signals in objective tests but proved unaffected in the subjective tests.

At –20 dB D/U, upper second adjacent FM IBOC signals increased the measured noise by 3 dB, while on the lower adjacent it increased noise by 11 dB. At –30 dB D/U the measurements indicate the CozmoCom did not fail but performed poorly with noise measurements of 4 to 6.5 dB WQP.

The subjective testing was unaffected by the addition of an FM IBOC signal to the second adjacent channels with a –10 dB D/U ratio, showing only a couple of tenths of a dB difference in noise levels. At –30 dB D/U, the CozmoCom was in total failure with an analog-only second adjacent subjective test signal.

ComPol Receiver

The other 92 kHz subcarrier receiver, the ComPol, showed the most severe reduction in performance with second adjacent FM IBOC signals. The objective and subjective test results tracked fairly closely.

At –10 dB D/U there was no meaningful change in performance with both the objective and subjective tests in the presence of second adjacent FM IBOC. At –30 dB D/U, the objective tests begin with substantial noise (9-13 dB WQP) and go into failure when the FM IBOC signals are added to second adjacencies. Similarly, the subjective tests at –30 dB D/U go from nearly bad (1.1 to 1.6 MOS) to failure with FM IBOC on second adjacencies.

The –20 dB D/U point was only tested in the objective tests. The objective tests at –20 dB D/U show a significant increase in received noise with the addition of FM IBOC on second adjacencies, 14 dB. Because it falls between the unaffected –10 and the at-failure –30 dB D/U levels, the –20 test is in the midst of the ComPol receiver’s transition to interference failure.

The ComPol receiver showed a measurable and significant reduction in performance only at the –20 dB D/U level when FM IBOC signals were added on second adjacencies. The performance with and without FM IBOC signals was essentially equalized at –30 dB D/U. The data suggest that the addition of FM IBOC on second adjacencies does accelerate the failure of the ComPol in the presence of second adjacent FM signals.

General Observations on Second Adjacent IBOC Compatibility with Subcarriers

In general, subcarrier receivers are susceptible to all second adjacent FM signals at moderate interferer levels (considering that –40 dB D/U is the FCC limit and that the subcarrier receivers typically failed between –10 and –30 dB D/U). Receiver failure is accelerated by the addition of FM IBOC on second adjacencies.

The resolution of the objective tests is at 10 dB D/U steps. The data suggest that FM IBOC induced degradation of subcarrier reception is likely to occur when the undesired signal is within 10 dB or less of the level at which an analog-only signal would cause the same conditions.

Limitations of Tests

The tests are extremely valuable and meaningful to the evaluation of FM IBOC compatibility with subcarrier reception. More detailed study in the future may help characterize the obvious variabilities in subcarrier receiver performance due to signal levels, in-band noise, upper-versus-lower adjacencies, and D/U ratios, as well as their responses to the addition of FM IBOC signals.

Simplifications and assumptions were made to streamline the testing process and obtain a battery of data that was readily processed. They include:

- Use of a limited sample of subcarrier receivers, two on 67 kHz and two on 92kHz;
- Laboratory objective tests utilizing standard, and modified standard, test signals rather than typical program audio;
- Injection of AWGN to approximate field reception conditions;
- Use of customary field practices for setting up main and subcarrier modulation and compression, limiting the precision and repeatability of the setups;
- Use of limited range and resolution of Desired-to-Undesired signal ratios;
- Limited characterization of receivers under test;
- Field tests with a simple vertical antenna was positioned in the judgment of the testers by ear without more rigorous characterization of the multipath environment;
- Field tests on WPOC and lab tests on the CozmoCom receiver in which there is apparent crosstalk on the recorded samples for which there was insufficient time and resources to verify causes and regenerate the tests;
- Subjective testing was conducted, for consistency, with headphones rather than speakers like those utilized in the subcarrier receivers;
- Subjective testing was conducted without limiting audio frequencies to the effective passbands of speakers utilized in subcarrier reception.

Data Subcarrier Compatibility

It stands to reason that just as an increase in composite baseband noise affects analog subcarrier reception, an increase in composite baseband noise may affect reception of digital subcarriers. Baseband noise is increased by the presence of insufficiently filtered adjacent channel signals, strong co-channel signals, and the general level of background noise.

The iBiquity subcarrier test report, Appendix A pp. 23-38, shows the spectral baseband components demodulated by a Belar monitor under a variety of noise and interference conditions. This series of graphs illustrates how variables such as signal level, injected noise, main channel modulation, and the presence of FM IBOC signals affect the noise level in the subcarrier portion of the demodulated FM baseband. Individual receivers, with the myriad tradeoffs in cost, filtering methods, demodulators, mixing and amplification, and other factors, will present varying results given the same reception conditions.

RBDS Compatibility

For the RBDS subcarrier test, a commercial analyzer, the Audemat, was utilized to measure Block Error Rates on the received RDS subcarrier in the presence of various test conditions. Consumer receivers may perform differently. However, the Audemat permitted accurate tabulation of data reception errors, and its results should prove to be a useful benchmark in the analysis of FM IBOC compatibility with RBDS reception.

Under strong and moderate signal levels in the laboratory, with 3% and 10% RBDS injection, with and without injected AWGN, with and without main channel modulation, RBDS reception exhibited no block errors (to a precision of 0.00%). Similarly, in first and second adjacent channel tests, with moderate signal levels, over a range of desired-to-undesired signal levels, with and without AWGN, there were no data errors.

Limited field tests were conducted on host RBDS reception to see whether they confirm the laboratory tests. Three locations were selected based on their approximate analog-only block error rates—0%, 1% and 10%. The injection of the RBDS subcarrier was 1 to 2%.

With the introduction of FM IBOC, the 0% location continued to deliver 0% errors over a 30-minute period.

At the 1% error location, the three three-minute analog-only samples ranged from 1.2 to 2.6% block errors. With FM IBOC on, three three-minute samples, which were alternated in time with the analog-only samples, yielded errors from 1.3% to 2.7 %. Clearly, at this level of resolution, the only variable in the error rate was a variation over time that resulted in the highest error rates being about double the lowest error rates. Perhaps with a much longer sample time, one could accumulate sufficient data to characterize the changes in error rates over time and determine if there are any subtle effects caused by the addition of FM IBOC signals to the host.

At the location yielding 10% errors, the analog-only rates ranged from 9.4 to 12.4% over three three-minute samples. With FM IBOC on, the rates ranged from 6.1 to 13.4%. As with the 1% test data, this data illustrates there is no obvious deterioration in error rates due to the addition of FM IBOC to the host station.

There is no indication of any incompatibility between FM IBOC signals and the reception of RBDS.

DARC Compatibility

Tests of the 76 kHz DARC digital subcarrier reception were performed with a commercially available DARC receiver. The received data stream was tested for errors both before and after the receiver's error correction stage.

Host Compatibility

Testing FM IBOC on the host signal, with moderate and strong signal levels, and with and without AWGN and main channel modulation, no block errors were detected prior to error correction.

In field tests, four locations with impaired reception were tested. One location was tested for a total of 30 minutes with host FM IBOC on, and 30 minutes with host analog only. The FM IBOC was turned on and off for ten-minute intervals over the period until each mode had accumulated thirty minutes of data. This represents nearly 100,000 blocks of data for each mode.

The raw received data in the thirty-minute tests, prior to error correction, indicated 0.00% error rate in analog-only mode, and 0.074% with FM IBOC. After error correction, the rates were zero.

At two locations the uncorrected error rates without FM IBOC were between 0.13 and 0.38% (plus an unusual value of 0.9%). With FM IBOC present, the uncorrected errors ranged from 0.15 to 0.37%. After error correction, all values were zero (except the unusually high analog-only measurement which resulted in a 0.232% post correction error rate). These tests included three three-minute samples of each mode at each location, for a total of 12 samples.

In the field tests with uncorrected error rates below 0.4% there is no apparent increase in errors due to the addition of FM IBOC to the host signal.

The remaining field test was run at a location with 6.2 to 9.9% uncorrected errors without FM IBOC. With FM IBOC, the uncorrected errors ranged from 7.7 to 10.8%. After error correction, the errors without FM IBOC ranged from 0.00% to 0.08%. With FM IBOC, the errors ranged from 0.02% to 0.1%. While these data may appear to hint at a slight increase in error rates with FM IBOC on, the apparent change is not statistically significant due to the limited number of samples (three three-minute samples each—FM IBOC on and off) and the large variations in errors over time.

The tests at approximately 10% uncorrected error rates do not indicate a significant change in error rates with the addition of FM IBOC to the host.

First Adjacent Compatibility

The first adjacent channel tests yielded significant block errors without FM IBOC present under certain conditions. At +16 dB D/U and in the absence of FM IBOC, block errors ranged about 1 to 2% prior to correction. These errors were fully corrected by the error correction scheme. At +6 dB D/U the pre-corrected block errors rose to 70-80%. Clearly, first adjacent signals at this ratio present a significant challenge to the DARC receiver. It is a testament to the robustness for the error corrector that these errors were reduced to a post-correction range of 1½ to 5%.

With the addition of FM IBOC on the first adjacent signal, no new errors were found in modes where errors had not previously occurred. The +16 dB D/U errors remained close to the analog-only errors, with the confidence intervals overlapping. These errors were fully corrected as were the analog-only errors in the same conditions.

At +6 dB D/U, the massive pre-correction errors increased by 1-2% with the addition of FM IBOC, still within overlapping confidence intervals of the analog-only results. Similarly, the corrected data at +6 dB D/U was very close to that of the analog-only tests, within the confidence intervals of the results.

There is a clear trend that shows a slight increase in errors with the presence of FM IBOC on first adjacent channels at +6 and +16 dB D/U, where there are already similar magnitude errors on the analog-only results. However, this trend is not statistically significant due to the overlapping confidence intervals of the results. More importantly, if this trend is indeed representative of the behavior of the DARC receiver in the presence of FM IBOC, it remains an extremely positive indication of compatibility. Small errors on both the analog-only and the FM IBOC signals are readily corrected under the same reception circumstances. Huge errors observed with analog-only first adjacent signals are incompletely corrected to the same magnitude of error as the huge errors that occur in the presence of analog with FM IBOC on first adjacent signals.

Second Adjacent Compatibility

Overall, the second adjacent compatibility data shows no impact of second adjacencies on the reception of DARC data. Error rates before correction were almost entirely zero with and without FM IBOC present. The –30 dB D/U ratio with the lower second adjacency produced fully correctable errors of less than 0.1% both with and without FM IBOC present.

Limitations of Testing

The most obvious variable observed in the field tests was that of reception quality over time. The data error rates obtained in the host field tests showed in some cases a 2 to 1 variation over only three three-minute samples. (One sample indicated a possible 4 to 1 variation). These tests do not provide the degree of resolution necessary to determine whether the addition of FM IBOC to the host signal causes any subtle but consistent variation in DARC reception.

First and second adjacent channel FM IBOC signals are not readily isolated as variables in field tests such that field-testing adjacent interference was not a part of this test plan. The laboratory tests show some consistently higher error rates for first adjacent channel reception with FM IBOC present. These differences in rates are statistically insignificant.

DARC Subcarrier Reception Compatibility Conclusion

FM IBOC signals are compatible with reception of DARC subcarrier data. Reception of the DARC data subcarrier at moderate signal levels is unaffected by the addition of FM IBOC signals to the host or to first or second adjacent signals.

Attachment 1 - Analog Subcarrier Receiver Characterization Tests

These tests were designed to insure that each receiver was meeting basic performance parameters prior to IBOC compatibility testing. The first column of the table below lists the characterization tests. The test procedure for these tests is on page 13 of the of the SC receiver characterization report which follows.

All tests were conducted with 10% subcarrier injection and 5 kHz deviation for both subcarrier frequencies (67 kHz and 92 kHz).

The RMS S/N was measured at five levels -85, -75, -65, -55, and -45 dBm. Only the -62 dBm S/N is listed in the Table. The S/N at the five levels is listed in the complete data report.

For the 1st adjacent tests the undesired transmitter was modulated with a 1kHz tone and deviated 75kHz. The tests were conducted on the upper and lower first adjacent channels at 16dB and 6dB D/U ratios. The results are WQP S/N.

Changes in 67 kHz subcarrier WQP S/N with and without 57kHz 3% RDS were measured at a signal level of -45 dBm.

Page 7 of the complete test data report lists the SC generator calibration data. Pages 8 through 12 show subcarrier calibration plots.

Summary of Analog Subcarrier Receiver Characterization Measurements

Make	CozmoCom	CozmoCom	Compol	McMartin	McMartin
Model	---	---	SCA-BL	TR-E5/55M	---
Serial Number	0073696	0073696	Sample 1001	286834	A0012461
SC Frequency	67 kHz	92 kHz	92 kHz	67 kHz	67 KHz
THD _45dBm 1kHz tone	1.0 V RMS 1.5% THD	1.0 V RMS 1.8% THD	0.5 V RMS 1.9% THD	0.175 V RMS 0.57% THD	1.0 V RMS 2.6% THD
S/N RMS at -65dBm (dB)	59	57	54	63	56
U 1st 16dB D/U WQP S/N (dB)	24	35	27	30	26
L 1st 16dB D/U WQP S/N (dB)	26	32	24	32	29
U 1st 6dB D/U WQP S/N (dB)	19	22	18	4	17
L 1st 6dB D/U WQP S/N (dB)	19	22	15	22	20
WQP S/N without and with 3% RDS (dB)	50/47	49/49	36/34	49/43	42/33

FM Receiver Test Laboratory

Date: 3/31/2001
Engineers: RMc
Project: SCA RX Characterization

Scope:

Basic SCA receiver tests to ensure that test radios are in good working condition for compatibility testing and to baseline receiver performance at a basic level. Further testing to be defined at a later date.

SCA receiver tests include:

1. Standard test audio output level (volume control calibration) and distortion
   SCA at 10% injection, 5kHz deviation, -45dBm RF level
   Audio measured RMS

2. Signal, noise curve at RF levels from -45dBm to -85dBm, 10dB resolution
   Audio measured RMS

3. First Adjacent selectivity using FM adjacent signal modulated 1kHz tone, 75kHz deviation at 16 and 6dB D/U
   Audio measured Weighted Quasi Peak (WQPK)

4. SCA receiver performance with and without 57kHz RBDS subcarrier
   Audio measured Weighted Quasi Peak (WQPK)

Receivers

1. CozmoCom FM portable radio with SCA audio for both 67kHz and 92kHz

2. Compol dedicated SCA receiver for 92kHz

3. McMartin dedicated SCA receiver for 67kHz

4. McMartin dedicated SCA receiver for 92kHz

FM Receiver Test Laboratory

Date: ######
Engineers: RMc
Project: SCA RX Characterization

Receiver Test No.:
Class: Portable
Radio Mfg.: CozmoCom
Model: FM Radio Receiver
Serial: 0073696

Antenna Network: None FM

RF Channel Frequency
RF: 97.90 MHz

Subcarrier Frequency

SCA: 67 kHz
Injection: 10 %

1 Standard Audio Output
RF Lev.: -45 dBm

Level: 1.00 Vrms

THD: 1.50 %

2 Curve test

RF Level (dBm)	Signal (dBr)	Noise (dBr)
-85.00	-0.50	-39.00
-75.00	0.00	-49.00
-65.00	0.00	-58.50
-55.00	0.00	-66.00
-45.00	0.00	-70.00

3 Selectivity 1st Adj
Desired: -45 dBm
Undesired: +/- 200kHz, 1kHz, 75kHz Dev
Measurement: WQPK Signal-to-Noise ratio

		S/N	
No Interference		50.00	dB
D/U (dB)	Upper	23.90	dB
16	Lower	25.80	dB
D/U (dB)	Upper	19.20	dB
6	Lower	18.50	dB

4 SC WQPK S/N With and Without 57kHz RBDS (3% / 2.25kHz)
Desired: -45 dBm
Undesired: None
Measurement: WQPK Signal-to-Noise ratio

	S/N	
Without 57kHz	50.00	dB
With 57kHz	48.50	dB

FM Receiver Test Laboratory

Date: ######
Engineers: RMc
Project: SCA RX Characterization

Receiver Test No.:
Class: Portable
Radio Mfg.: CozmoCom
Model: FM Radio Receiver
Serial: 0073696

Antenna Network: None FM

RF Channel Frequency
RF: 97.90 MHz

Subcarrier Frequency

SCA: 92 kHz
Injection 10 %

1 Standard Audio Output
RF Lev.: -45 dBm

Level: 1.00 Vrms

THD: 1.80 %

2 Curve test

RF Level (dBm)	Signal (dBr)	Noise (dBr)
-85.00	0.00	-37.25
-75.00	0.00	-47.00
-65.00	0.00	-57.00
-55.00	0.00	-65.00
-45.00	0.00	-69.00

3 electivity 1st Adj
Desired: -45 dBm
Undesired: +/- 200kHz, 1kHz, 75kHz Dev
Measurement: WQPK Signal-to-Noise ratio

		S/N	
No Interference		49.00	dB
D/U (dB)	Upper	34.50	dB
16	Lower	32.20	dB
D/U (dB)	Upper	22.00	dB
6	Lower	21.50	dB

4 SC WQPK S/N With and Without 57kHz RBDS (3% / 2.25kHz)
Desired: -45 dBm
Undesired: None
Measurement: WQPK Signal-to-Noise ratio

	S/N	
Without 57kHz	49.00	dB
With 57kHz	49.00	dB

FM Receiver Test Laboratory

Date: ######
Engineers: RMc
Project: SCA RX Characterization

Receiver Test No.:
Class: Table
Radio Mfg.: ComPol
Model: SCA-BL
Serial: Sample 1001

Comments:
This receiver has a problem when tur
past a certain point the audio goes int
Therefore the audio output level was

Antenna Network: None FM

RF Channel Frequency
RF: 97.90 MHz

Subcarrier Frequency

SCA: 92 kHz
Injection 10 %

1 Standard Audio Output
RF Lev.: -45 dBm

Level: 0.50 Vrms

THD: 1.90 %

2 Curve test

RF Level (dBm)	Signal (dBr)	Noise (dBr)
-85.00	0.00	-37.50
-75.00	0.00	-47.00
-65.00	0.00	-54.25
-55.00	0.00	-57.25
-45.00	0.00	-57.50

3 electivity 1st Adj
Desired: -45 dBm
Undesired: +/- 200kHz, 1kHz, 75kHz Dev
Measurement: WQPK Signal-to-Noise ratic

		S/N	
No Interference		35.60	dB
D/U (dB)	Upper	27.00	dB
16	Lower	24.30	dB
D/U (dB)	Upper	17.80	dB
6	Lower	15.00	dB

4 SC WQPK S/N With and Without 57kHz RBDS (3% / 2.25kHz)
Desired: -45 dBm
Undesired: None
Measurement: WQPK Signal-to-Noise ratic

	S/N	
Without 57kHz	35.60	dB
With 57kHz	34.20	dB

FM Receiver Test Laboratory

Date: ######
Engineers: RMc
Project: SCA RX Characterization

Receiver Test No.:
Class: Table
Radio Mfg.: McMartin
Model: TR-E5/55M
Serial: 286834

Comments:
Output at line level at jack on rear pa
Volume control does not affect audic
audio output jack on rear panel

Antenna Network: None FM

RF Channel Frequency
RF: 97.90 MHz

Subcarrier Frequency

SCA: 67 kHz
Injection 10 %

1 Standard Audio Output
RF Lev.: -45 dBm

Level: 0.175 Vrms

THD: 0.57 %

2 Curve test

RF Level (dBm)	Signal (dBr)	Noise (dBr)
-85.00	0.00	-42.00
-75.00	0.00	-52.25
-65.00	0.00	-62.00
-55.00	0.00	-63.00
-45.00	0.00	-64.00

3 electivity 1st Adj
Desired: -45 dBm
Undesired: +/- 200kHz, 1kHz, 75kHz Dev
Measurement: WQPK Signal-to-Noise ratic

		S/N	
No Interference		49.00	dB
D/U (dB)	Upper	30.30	dB
16	Lower	32.20	dB
D/U (dB)	Upper	4.16	dB
6	Lower	21.70	dB

4 SC WQPK S/N With and Without 57kHz RBDS (3% / 2.25kHz)
Desired: -45 dBm
Undesired: None
Measurement: WQPK Signal-to-Noise ratic

	S/N	
Without 57kHz	49.00	dB
With 57kHz	42.60	dB

FM Receiver Test Laboratory

Date: ######
Engineers: RMc
Project: SCA RX Characterization

Receiver Test No.:
Class: Table
Radio Mfg.: McMartin
Model: Unsure - Comm Center R9
Serial: A0012461

Comments:
Audio output is headphone output on
(varies with volume control)

Antenna Network: None FM

RF Channel Frequency
RF: 97.90 MHz

Subcarrier Frequency

SCA: 67 kHz
Injection 10 %

1 Standard Audio Output
RF Lev.: -45 dBm

Level: 1.000 Vrms

THD: 2.60 %

2 Curve test

RF Level (dBm)	Signal (dBr)	Noise (dBr)
-85.00	-0.25	-39.50
-75.00	-0.25	-48.50
-65.00	0.00	-55.75
-55.00	0.00	-59.00
-45.00	0.00	-60.00

3 electivity 1st Adj
Desired: -45 dBm
Undesired: +/- 200kHz, 1kHz, 75kHz Dev
Measurement: WQPK Signal-to-Noise ratio

		S/N	
No Interference		42.60	dB
D/U (dB)	Upper	26.40	dB
16	Lower	29.30	dB
D/U (dB)	Upper	17.20	dB
6	Lower	20.00	dB

4 SC WQPK S/N With and Without 57kHz RBDS (3% / 2.25kHz)
Desired: -45 dBm
Undesired: None
Measurement: WQPK Signal-to-Noise ratio

	S/N	
Without 57kHz	42.40	dB
With 57kHz	33.30	dB

FM Receiver Test Laboratory

3/31/2001
RMc
SCA Generator Calibration Data
For 5kHz deviation

SCA Gen	**Mod Sci Sidekick**	
SCA Freq	67	kHz
Mod Freq	400	Hz
Input	1,2	Unbal
Input Lev	1.08	Vrms

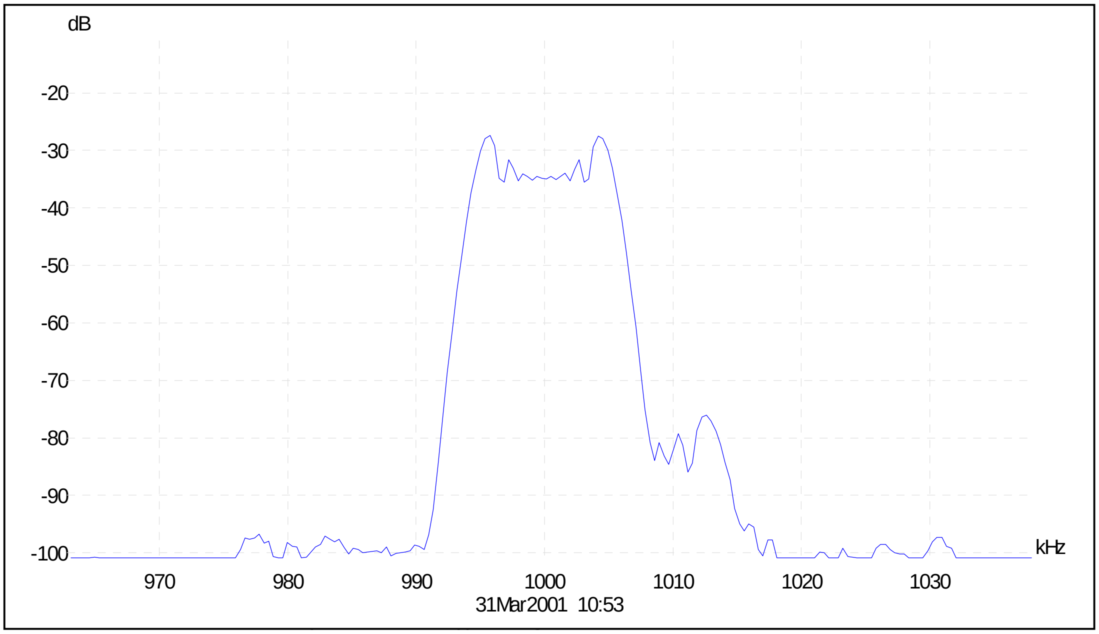
SCA Gen	**Mod Sci Sidekick**	
SCA Freq	92	kHz
Mod Freq	400	Hz
Input	1,2	Unbal
Input Lev	1.08	Vrms

RE533 RBDS Generator

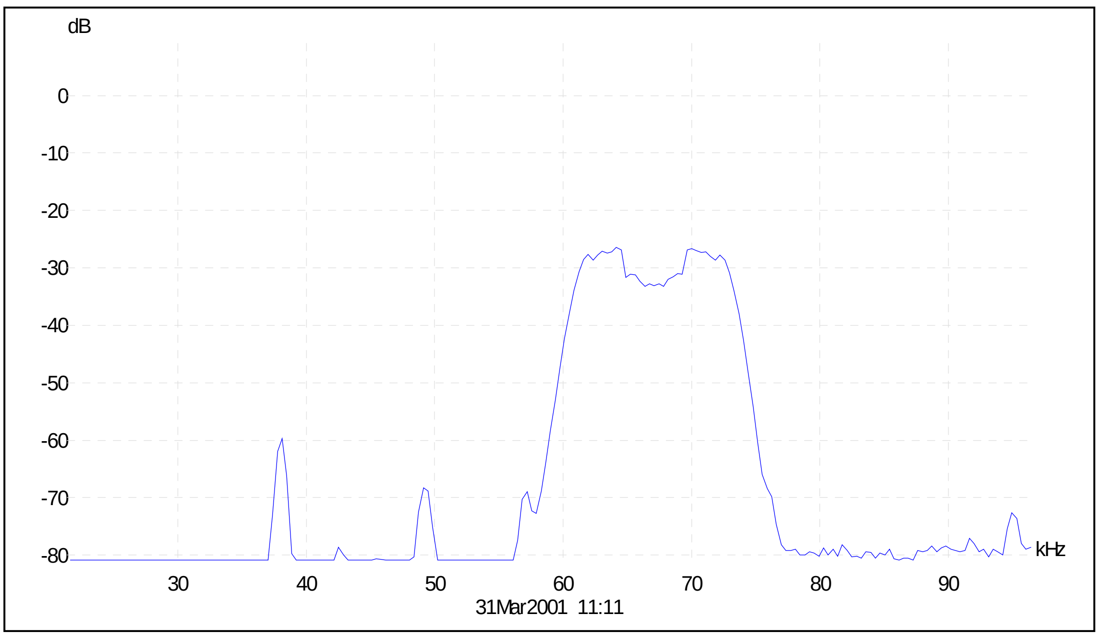
SCA Freq	57	kHz	
Phase Lock	19	kHz	(Pilot)

FM Receiver Test Laboratory

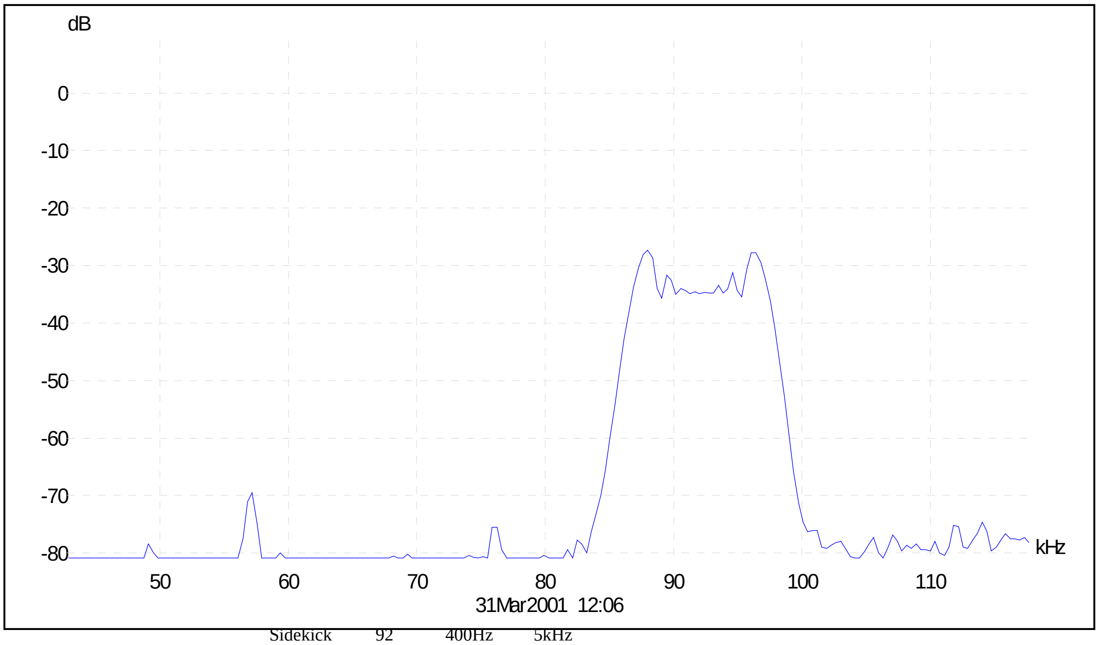
Initial plot of RE107 calibrated to Modulation analyzer establishes reference plot of spectrum analyzer.
Plot of Modulation Analyzer output



Plot of 67kHz SCA signal from Modulation Analyzer output

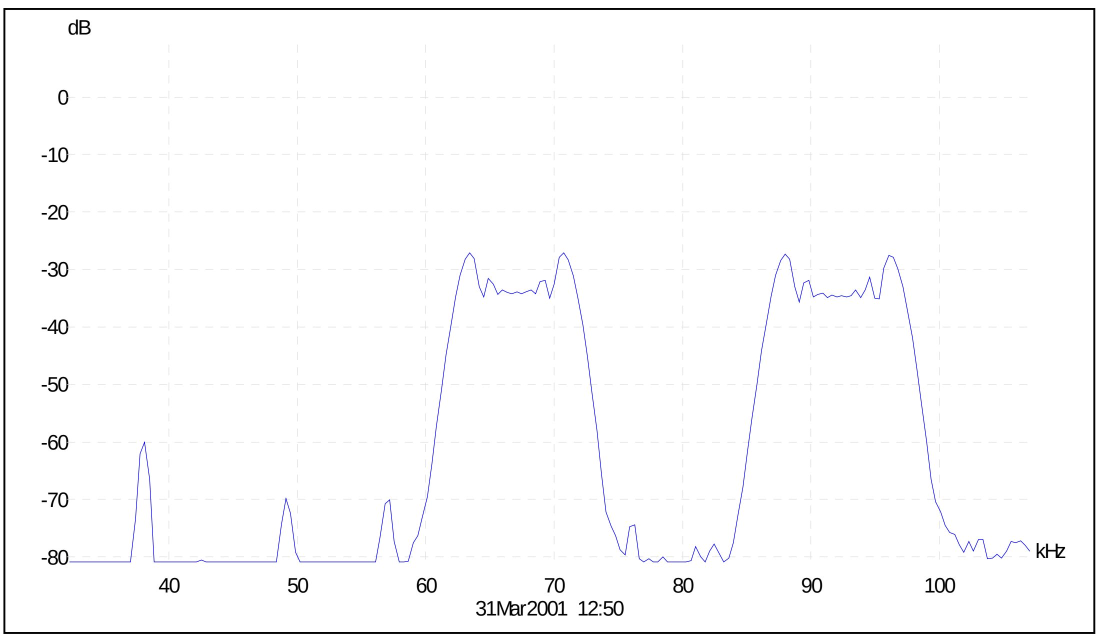


Plot of 92kHz SCA signal from Modulation Analyzer output

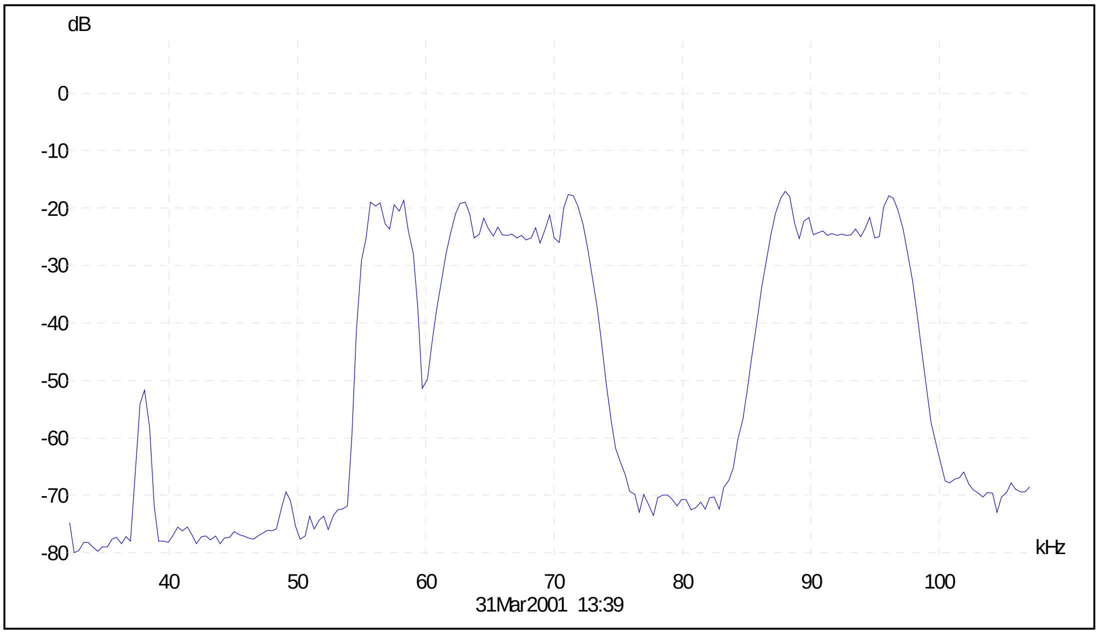


Sidekick 92 400Hz 5kHz

Plot of 67kHz and 92kHz SCA signals from Modulation Analyzer output



Plot of 57kHz, 67kHz and 92kHz SCA signals from Modulation Analyzer output



FM Receiver Test Laboratory

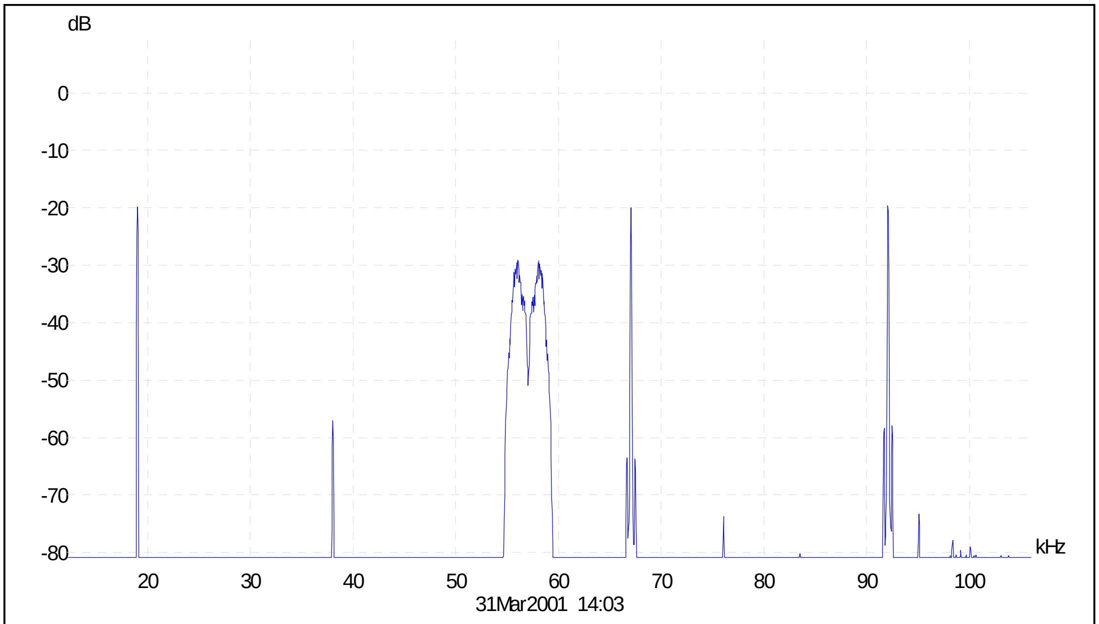
3/31/2001 RMc

Spectrum Analyzer

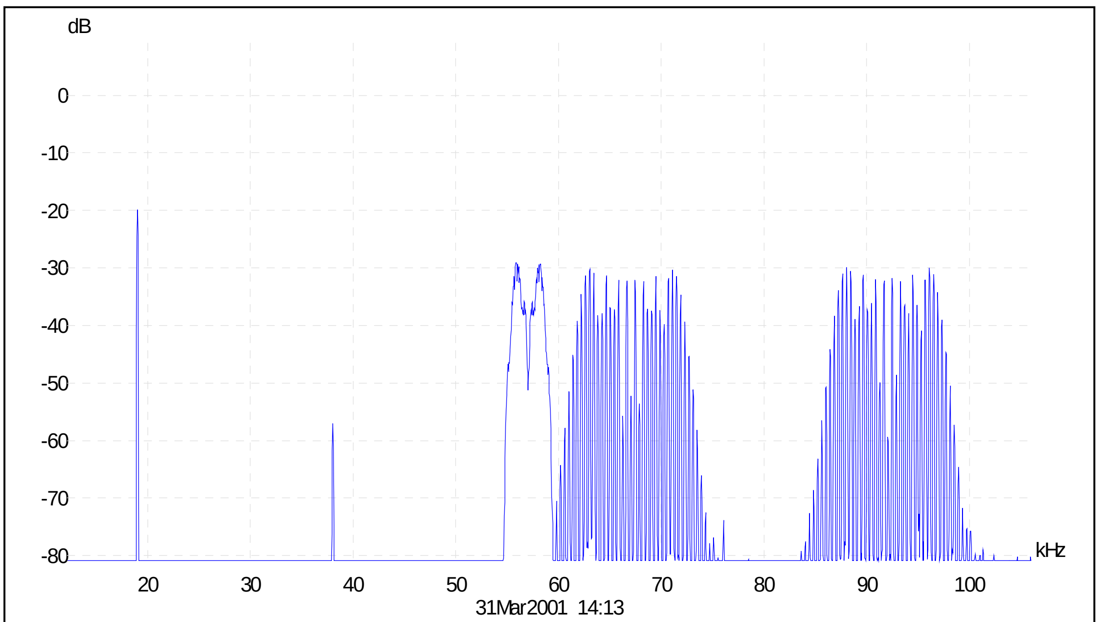
Type:	Pico ADC 212	
Input:	Fixed	
Level:	1	V
Timebase:	187	kHz
Mag:	2	X
Window:	Blackman	
No. of Bands:	4096	Bins
Disp. Mode:	Peak	

Source

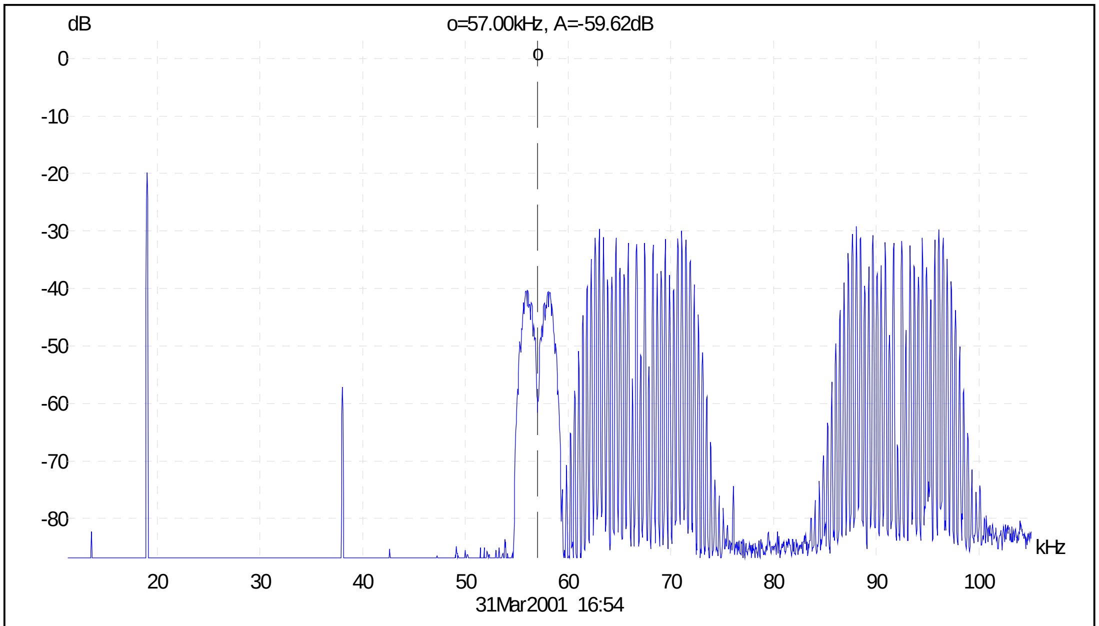
Type:	AFM 2	
Meter range:	30	kHz
Filter Set:	200	kHz (wide)



-20dB	10% injection	
19	kHz	10%
57	kHz	10%
67	kHz	10%
92	kHz	10%



-20dB	10% injection		Deviation	
19	kHz	10%	NA	
57	kHz	10%	Std RDS	
67	kHz	10%	5	kHz
92	kHz	10%	5	kHz



-20dB	10% injection		Deviation	
19	kHz	10%	NA	
57	kHz	3%	Std RDS	
67	kHz	10%	5	kHz
92	kHz	10%	5	kHz

Appendix K –
NRSC Industry Subjective Evaluation

NATIONAL
RADIO
SYSTEMS
COMMITTEE

DAB Subcommittee
Evaluation of the iBiquity Digital Corporation IBOC System

Part 1 – FM IBOC

November 7, 2001

To: NRSC Evaluation Working Group

From: iBiquity Digital Corporation

Re: FM Industry Evaluation

Attached to this memorandum are the results from the NRSC FM Industry Evaluation conducted September 5-7, 2001 at the NAB Radio Show in New Orleans. Sixty-one participants were trained, screened and tested. Of these 61 participants, 3 were excluded for failing the screening test, and 2 were excluded for not finishing the experiment. Thus, results from 56 participants are reported in the attached NRSC Industry Evaluation Performance and Compatibility Tables. Fifty-five males and 1 female participated. Table 1 is a breakdown of participants by age.

Table 1: Breakdown of participants by age

18-29	1
30-39	14
40-49	27
50-59	17
60+	2

Jennifer Devlin and Ellyn Sheffield of iBiquity conducted all training, screening and testing. All methodological practices used at Dynastat during the FM Test Program were followed as closely as possible, including method of presentation, analysis of screening results, and preparation of results (i.e., tables with confidence intervals).

A subset of the sound samples evaluated at Dynastat in the overall subjective evaluation program was compiled for the Industry Evaluation. Samples were taken from the field performance, field compatibility, lab performance and lab compatibility portions of the test program. No SCA audio samples were included. Samples were divided into three experiments, leveled and presented to participants over Sennheiser headphones. Data from all experiments were combined for analysis after testing was completed.

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FIELD PERFORMANCE WITH 1st ADJACENT INTERFERENCE
(INDUSTRY EVALUATION)

			Classical			Country/Rock			Speech/VoiceOver		
Receiver	**D/U**	**Data**	**IBOC**	**Delphi**	**Pioneer**	**IBOC**	**Delphi**	**Pioneer**	**IBOC**	**Delphi**	**Pioneer**
WETA	+23	MOS	4.6	3.9	3.8						
		Confid Interval (+/-)	0.15	0.26	0.22						
	+22	MOS							4.6	4.1	3.9
		Confid Interval (+/-)							0.62	0.72	0.85
	+20	MOS	4.6	2.9	3.0						
		Confid Interval (+/-)	0.22	0.28	0.30						
	+19	MOS							3.2	1.9	1.7
		Confid Interval (+/-)							0.41	0.28	0.30
	+14	MOS	4.6	2.4	2.6						
		Confid Interval (+/-)	0.31	0.36	0.36						
	+9	MOS							4.8	2.9	3.0
		Confid Interval (+/-)							0.28	0.35	0.36
WNEW	+16	MOS							3.8	1.5	1.1
		Confid Interval (+/-)							0.34	0.28	0.10
	+13	MOS							3.3	1.6	1.3
		Confid Interval (+/-)							0.49	0.27	0.21
WPOC	+19	MOS							4.0	4.1	3.9
		Confid Interval (+/-)							0.42	0.25	0.43
	+16	MOS				4.9	4.5	4.5			
		Confid Interval (+/-)				0.13	0.26	0.26			
	+13	MOS				4.4	3.9	3.7			
		Confid Interval (+/-)				0.29	0.31	0.39			

FIELD PERFORMANCE WITH 2nd ADJACENT INTERFERENCE (INDUSTRY EVALUTAION)

	Lower/			Classical			Country/Rock			Speech/VoiceOver		
Station	**Upper**	**D/U dB**	**Data**	**IBOC**	**Delphi**	**Pioneer**	**IBOC**	**Delphi**	**Pioneer**	**IBOC**	**Delphi**	**Pioneer**
KLLC	Upper	-28	MOS				2.8	2.5	1.5			
			CI (+/-)				0.61	0.25	0.31			
		-23	MOS				2.9	2.3	2.1			
			CI (+/-)				0.49	0.3	0.28			
		-21	MOS				3.0	2.2	2.0			
			CI (+/-)				0.59	0.36	0.39			
		-19	MOS							3.0	1.7	1.4
			CI (+/-)							0.56	0.25	0.22
		-18	MOS				3.1	2.1	1.8			
			CI (+/-)				0.38	0.33	0.28			
		-17	MOS							2.6	1.6	1.4
			CI (+/-)							0.47	0.31	0.25
WD2XAB	Lower	-2	MOS	4.5	2.4	2.1						
			CI (+/-)	0.4	0.36	0.5						
WNEW	Lower	-18	MOS							3.4	3.0	3.1
			CI (+/-)							0.26	0.31	0.37

ACENT INTERFERERS (INDUSTRY EVALUATION)

			Rock			Voice Over		
Upper	Lower	Data	IBOC	Delphi	Pioneer	IBOC	Delphi	Pioneer
-31	-25	MOS	3.8	3.0	3.3			
		Confid Interval (+/-)	0.52	0.40	0.55			
-26	-33	MOS	4.0	3.3	3.8			
		Confid Interval (+/-)	0.42	0.39	0.47			
-24	-22	MOS				4.1	3.7	3.6
		Confid Interval (+/-)				0.26	0.29	0.27
-24	-12	MOS	3.9	2.2	1.9			
		Confid Interval (+/-)	0.40	0.32	0.38			
-18	-15	MOS	4.1	3.4	3.7			
		Confid Interval (+/-)	0.34	0.35	0.37			
-15	-33	MOS	3.6	2.9	2.6			
		Confid Interval (+/-)	0.27	0.28	0.31			
-14	-11	MOS				3.6	2.9	2.8
		Confid Interval (+/-)				0.37	0.33	0.42

FIELD PERFORMANCE AT BLEND (INDUSTRY EVALUATION)

	Classical			Rock			Speech		
	IBOC	**Delphi**	**Pioneer**	**IBOC**	**Delphi**	**Pioneer**	**IBOC**	**Delphi**	**Pioneer**
MOS	2.9	2.3	2.2	3.7	3.2	3.6	2.5	2.2	2.1
Confid Interval (+/-)	0.21	0.20	0.21	0.22	0.28	0.25	0.28	0.31	0.24

FIELD PERFORMANCE WITH MULTIPATH (INDUSTRY EVALUATION)

				Country			Rock			Voice Over			Speech		
Station	**Mutipath**	**Instensity**	**Data**	**IBOC**	**Delphi**	**Pioneer**	**IBOC**	**Delphi**	**Pioneer**	**IBOC**	**Delphi**	**Pioneer**	**IBOC**	**Delphi**	**Pioneer**
KLLC	Terrain	Light	MOS				4.7	3.5	3.9						
	Obstruct		CI (+/-)				0.23	0.47	0.40						
		Mod	MOS				4.4	2.4	2.6	4.7	2.6	2.2			
			CI (+/-)				0.16	0.21	0.20	0.20	0.35	0.36			
		Severe	MOS				3.8	2.8	2.4						
			CI (+/-)				0.20	0.21	0.30						
KWNR	Spectral	Light	MOS	4.1	4.0	4.1				4.2	3.0	3.1			
			CI (+/-)	0.28	0.34	0.35				0.66	0.63	0.57			
		Mod	MOS	3.9	2.4	2.2				3.3	2.4	2.1			
			CI (+/-)	0.26	0.20	0.20				0.45	0.37	0.19			
		Severe	MOS	3.9	2.4	2.2				3.7	2.3	1.7	3.7	2.3	1.5
			CI (+/-)	0.37	0.35	0.29				0.47	0.31	0.29	0.33	0.21	0.20

FIELD COMPATIBILITY - HOST (INDUSTRY EVALUATION)

		Classical		Country/Rock		Speech	
		No IBOC	IBOC	No IBOC	IBOC	No IBOC	IBOC
Delphi	MOS	3.7	4.0	3.6	4.0	3.1	3.4
	Confid Interval (+/-)	0.53	0.31	0.37	0.29	0.39	0.35
Pioneer	MOS	4.1	4.3	4.1	4.2	3.2	3.1
	Confid Interval (+/-)	0.33	0.39	0.38	0.32	0.35	0.32
Sony	MOS	3.8	3.9	4.1	4.2	2.4	2.6
	Confid Interval (+/-)	0.33	0.46	0.40	0.32	0.34	0.41
Technics	MOS	4.1	4.3	3.8	3.6	3.2	3.2
	Confid Interval (+/-)	0.35	0.30	0.26	0.39	0.38	0.38

FIELD COMPATIBILITY - 1ST ADJACENT INTERFERENCE (INDUSTRY EVALUATION)

Receiver	D/U	Data	Classical No IBOC	Classical IBOC	Country/Rock No IBOC	Country/Rock IBOC	Speech No IBOC	Speech IBOC
Delphi	+6	MOS			3.7	3.6		
		Confid Interval (+/-)			0.33	0.37		
	-4	MOS			3.0	3.0		
		Confid Interval (+/-)			0.36	0.39		
	-6	MOS					2.6	2.5
		Confid Interval (+/-)					0.43	0.31
	-9	MOS	3.2	3.3				
		Confid Interval (+/-)	0.38	0.43				
	-11	MOS			3.3	3.1		
		Confid Interval (+/-)			0.37	0.36		
	-14	MOS			2.4	3.0		
		Confid Interval (+/-)			0.36	0.44		
Pioneer	+6	MOS			4.0	4.1		
		Confid Interval (+/-)			0.40	0.35		
	-4	MOS			3.4	3.1		
		Confid Interval (+/-)			0.42	0.37		
	-6	MOS					1.9	2.2
		Confid Interval (+/-)					0.28	0.37
	-9	MOS	2.6	2.6				
		Confid Interval (+/-)	0.31	0.31				
	-11	MOS			3.9	3.5		
		Confid Interval (+/-)			0.25	0.42		
	-14	MOS			3.5	2.8		
		Confid Interval (+/-)			0.44	0.49		
Sony	+6	MOS			3.0	3.1		
		Confid Interval (+/-)			0.37	0.46		
Technics	+6	MOS			4.0	4.1		
		Confid Interval (+/-)			0.42	0.42		

FIELD COMPATIBILITY - 1st ADJACENT MULTIPATH (INDUSTRY EVALUATION)

			Country/Rock	
Receiver	**D/U**	**Data**	**No IBOC**	**IBOC**
Delphi	-1	MOS	2.8	3.1
		Confid Interval (+/-)	0.61	0.40
	-9	MOS	3.1	3.0
		Confid Interval (+/-)	0.38	0.34
Pioneer	-1	MOS	3.4	2.8
		Confid Interval (+/-)	0.51	0.37
	-9	MOS	3.4	3.1
		Confid Interval (+/-)	0.42	0.31

LAB PERFORMANCE - AWGN WITHOUT AND WITH MULTIPATH (INDUSTRY EVALUATION)

Level of			CLASSICAL			ROCK			SPEECH		
AWGN	**Multipath Type**	**Data**	**IBOC**	**Delphi**	**Pioneer**	**IBOC**	**Delphi**	**Pioneer**	**IBOC**	**Delphi**	**Pioneer**
B-2dB	Rural Fast	MOS	4.7	2.2	2.2						
		Confid Interval (+/-)	0.25	0.29	0.35						
	Terrain Obstructed	MOS							4.7	1.8	1.8
		Confid Interval (+/-)							0.25	0.27	0.23
	Urban Fast	MOS				4.6	3.6	3.5			
		Confid Interval (+/-)				0.25	0.43	0.31			
	Urban Slow	MOS				4.9	2.8	3.3			
		Confid Interval (+/-)				0.20	0.32	0.41			

LAB PERFORMANCE - CO CHANNEL, SINGLE AND DUAL ADJ (INDUSTRY EVALUATION)

1st Interferer	Level of 1st interfer	2nd interferer	D/U of 2nd interferer	Data	CLASSICAL IBOC	CLASSICAL Delphi	CLASSICAL Pioneer	CLASSICAL Sony	CLASSICAL Technics	ROCK IBOC	ROCK Delphi	ROCK Sony	ROCK Technics
Co-Channel	b-2dB			MOS	4.0	failure	1.1	failure	1.0				
				CI (+/-)	0.54		0.13		0.09				
Lower 1st Adj	b-2dB			MOS						4.7	1.0	1.0	failure
				CI (+/-)						0.20	0.00	0.00	
		Upper 1st	+6db	MOS	3.9	4.0	4.1	1.1	2.3				
				CI (+/-)	0.47	0.47	0.55	0.17	0.42				
Lower 2nd Adj	b-2dB	Upper 1st	+6db	MOS	3.9	failure	failure	failure	2.7				
				CI (+/-)	0.47				0.46				
		Upper 2nd	-20dB	MOS	4.4	failure	failure	failure	2.6				
				CI (+/-)	0.27				0.35				

LAB PERFORMANCE - CO and 1ST ADJACENT WITH MULTIPATH (INDUSTRY EVALUATION)

1st Interferer	Level of interfer	2nd interferer	D/U of 2nd interfer	Type multi path	Data	CLASSICAL IBOC	CLASSICAL Delphi	CLASSICAL Pioneer	ROCK IBOC	ROCK Delphi	ROCK Pioneer
Co-Channel	B-8dB			RF	MOS				4.5	1.1	1.0
					CI (+/-)				0.31	0.16	0.10
				TO	MOS	4.6	1.2	1.1			
					CI (+/-)	0.22	0.17	0.14			
				US	MOS				3.5	1.1	1.1
					CI (+/-)				0.39	0.16	0.21
				UF	MOS	4.3	1.0	1.0			
					CI (+/-)	0.38	0.00	0.00			
Lower 1st Adj	B-8dB			RF	MOS	4.6	1.7	1.6			
					CI (+/-)	0.23	0.33	0.27			
				UF	MOS				4.7	2.0	2.1
					CI (+/-)				0.25	0.32	0.37
				US	MOS	4.3	2.1	2.7			
					CI (+/-)	0.37	0.28	0.30			
				TO	MOS				4.1	1.9	2.1
					CI (+/-)				0.25	0.22	0.30
		Upper 1st	+6	RF	MOS	4.6	2.9	3.2			
					CI (+/-)	0.25	0.33	0.48			
				TO	MOS	3.8	1.2	1.2			
					CI (+/-)	0.48	0.20	0.18			
				UF	MOS	3.9	3.6	3.9			
					CI (+/-)	0.33	0.34	0.44			
				US	MOS	4.4	2.9	3.2			
					CI (+/-)	0.36	0.35	0.32			

1st Interferer	Level of interfer	2nd interferer	D/U of 2nd interfer	Type multi path	Data	CLASSICAL IBOC	CLASSICAL Delphi	CLASSICAL Pioneer	ROCK IBOC	ROCK Delphi	ROCK Pioneer
Lower 2nd Adj	B-8dB			RF	MOS				4.4	2.8	2.8
					CI (+/-)				0.30	0.34	0.34
				TO	MOS	3.9	2.4	2.2			
					CI (+/-)	0.42	0.34	0.38			
				US	MOS				4.5	3.6	3.9
					CI (+/-)				0.31	0.41	0.50
				UF	MOS				4.7	4.3	4.2
					CI (+/-)				0.30	0.42	0.20
	B-8dB	Upper 1st	+6	RF	MOS				4.9	3.7	4.0
					CI (+/-)				0.10	0.42	0.42
				UF	MOS	4.4	3.2	2.0			
					CI (+/-)	0.36	0.37	0.51			
				US	MOS				3.5	3.1	3.0
					CI (+/-)				0.39	0.29	0.36
		Upper 2nd	-20	RF	MOS	4.8	2.4	1.4			
					CI (+/-)	0.19	0.31	0.23			
				TO	MOS				4.3	2.3	2.4
					CI (+/-)				0.33	0.35	0.36
				UF	MOS				4.6	3.4	3.3
					CI (+/-)				0.27	0.30	0.55
				US	MOS	4.1	3.2	3.3			
					CI (+/-)	0.38	0.46	0.43			

LAB PERFORMANCE - IMPULSE NOISE (INDUSTRY EVALUATION)

	Level of		Level of		CLASSICAL		
Interferer	**interferer (dB)**	**AWGN**	**AWGN**	**Data**	**IBOC**	**Delphi**	**Pioneer**
		120Hz	B-2dB	MOS	4.8	3.1	4.1
				CI (+/-)	0.17	0.35	0.32
		330Hz	B-2dB	MOS	4.8	3.1	3.9
				CI (+/-)	0.17	0.49	0.43
		RPRF	B-2dB	MOS	4.4	3.0	3.0
				CI (+/-)	0.23	0.34	0.37
		2000Hz	B-2dB	MOS	4.7	3.8	3.4
				CI (+/-)	0.23	0.38	0.43
Upper 1st	+6	120Hz	B-2dB	MOS	4.3	2.4	2.8
				CI (+/-)	0.33	0.43	0.61

LAB COMPATIBILITY - HOST (INDUSTRY EVALUATION)

Rx	AWGN	Data	Rock No IBOC	Rock IBOC	Speech No IBOC	Speech IBOC
Delphi	No Noise	MOS			4.0	3.9
		Confid Interval (+/-)			0.37	0.37
	30K	MOS	4.8	4.6		
		Confid Interval (+/-)	0.24	0.34		
Pioneer	No Noise	MOS			4.1	4.0
		Confid Interval (+/-)			0.30	0.43
	30K	MOS	4.5	4.7		
		Confid Interval (+/-)	0.28	0.20		
Sony	No Noise	MOS			3.9	2.6
		Confid Interval (+/-)			0.37	0.39
	30K	MOS	4.3	4.4		
		Confid Interval (+/-)	0.37	0.46		
Technics	No Noise	MOS			4.0	3.9
		Confid Interval (+/-)			0.34	0.34
	30K	MOS	4.5	4.7		
		Confid Interval (+/-)	0.35	0.26		

LAB COMPATIBILITY - 2ND ADJACENT INTERFERENCE (INDUSTRY EVALUATION)

					Classical		Rock		Speech	
	Upper/Lowe	D/U dB	AWGN	Data	No IBOC	IBOC	No IBOC	IBOC	No IBOC	IBOC
Delphi	Lower	-40	No Noise	MOS			3.9	3.7		
				Confid Interval (+/-)			0.29	0.32		
			30K	MOS					4.2	3.9
				Confid Interval (+/-)					0.31	0.27
		-20	30K	MOS			4.6	4.7		
				Confid Interval (+/-)			0.31	0.23		
	Upper	-40	No Noise	MOS					4.1	4.3
				Confid Interval (+/-)					0.29	0.28
			30K	MOS			4.1	3.8		
				Confid Interval (+/-)			0.31	0.43		
		-20	30K	MOS	4.6	4.3				
				Confid Interval (+/-)	0.61	0.67				
Pioneer	Lower	-40	No Noise	MOS			3.8	3.3		
				Confid Interval (+/-)			0.33	0.35		
			30K	MOS					4.0	4.0
				Confid Interval (+/-)					0.33	0.25
		-20	30K	MOS			4.8	4.6		
				Confid Interval (+/-)			0.20	0.25		
	Upper	-40	No Noise	MOS					4.2	4.2
				Confid Interval (+/-)					0.31	0.27
			30K	MOS			3.9	3.9		
				Confid Interval (+/-)			0.41	0.39		
		-20	30K	MOS	4.4	4.2				
				Confid Interval (+/-)	0.69	0.96				
Sony	Lower	-20	30K	MOS			3.5	1.8		
				Confid Interval (+/-)			0.51	0.38		
	Upper	-20	30K	MOS	2.2	1.9				
				Confid Interval (+/-)	0.83	0.52				
Technics	Lower	-40	No Noise	MOS			3.7	1.2		
				Confid Interval (+/-)			0.37	0.19		
			30K	MOS					2.7	1.3
				Confid Interval (+/-)					0.36	0.21
		-20	30K	MOS			4.4	4.5		
				Confid Interval (+/-)			0.40	0.25		

	Upper	-20	30K	MOS Confid Interval (+/-)	4.6 0.22	4.5 0.27		

LAB COMPATIBILITY --1ST ADJACENT INTERFERENCE (INDUSTRY EVALUTION)

	Condition	D/U dB	AWGN	Data	Classical No IBOC	Classical IBOC	Rock No IBOC	Rock IBOC	Speech No IBOC	Speech IBOC
Delphi	Lower	+16	No Noise	MOS	4.6	4.2				
				Confid Interval (+/-)	0.30	0.27				
			30K	MOS					3.5	3.2
				Confid Interval (+/-)					0.26	0.33
		+6	30K	MOS	4.1	2.9				
				Confid Interval (+/-)	0.35	0.31				
		-4	No Noise	MOS			4.4	3.8		
				Confid Interval (+/-)			0.35	0.37		
			30K	MOS			3.9	3.2		
				Confid Interval (+/-)			0.29	0.48		
	Upper	+16	30K	MOS			4.4	4.3		
				Confid Interval (+/-)			0.30	0.38		
			No Noise	MOS			4.2	4.6		
				Confid Interval (+/-)			0.37	0.31		
		+6	30K	MOS					3.5	2.1
				Confid Interval (+/-)					0.41	0.35
		-4	No Noise	MOS			4.5	3.9		
				Confid Interval (+/-)			0.27	0.35		
			30K	MOS	3.8	1.4				
				Confid Interval (+/-)	0.45	0.31				
Pioneer	Lower	+16	No Noise	MOS	4.7	4.3				
				Confid Interval (+/-)	0.23	0.33				
			30K	MOS					3.3	2.6
				Confid Interval (+/-)					0.34	0.35
		+6	30K	MOS	3.9	2.8				
				Confid Interval (+/-)	0.38	0.35				
		-4	No Noise	MOS			4.5	3.6		
				Confid Interval (+/-)			0.31	0.47		
			30K	MOS			4.0	3.8		
				Confid Interval (+/-)			0.39	0.33		
	Upper	+16	30K	MOS			4.5	4.1		
				Confid Interval (+/-)			0.37	0.44		
			No Noise	MOS			4.1	4.0		

				Confid Interval (+/-)			0.46	0.44		
		+6	30K	MOS					3.4	2.0
				Confid Interval (+/-)					0.33	0.28
		-4	No Noise	MOS			4.4	3.4		
				Confid Interval (+/-)			0.30	0.42		
			30K	MOS	3.6	1.4				
				Confid Interval (+/-)	0.44	0.36				

Sony	Lower	+16	No Noise	MOS	3.1	2.9				
				Confid Interval (+/-)	0.73	0.55				
			30K	MOS					2.0	2.0
				Confid Interval (+/-)					0.32	0.29
		+6	30K	MOS	1.4	1.4				
				Confid Interval (+/-)	0.27	0.22				
		-4	No Noise	MOS			1.1	1.0		
				Confid Interval (+/-)			0.17	0.00		
			30K	MOS			2.0	1.6		
				Confid Interval (+/-)			0.38	0.26		
	Upper	+16	30K	MOS			2.9	3.2		
				Confid Interval (+/-)			0.45	0.43		
			No Noise	MOS			3.9	3.8		
				Confid Interval (+/-)			0.47	0.46		
		+6	30K	MOS					1.3	1.3
				Confid Interval (+/-)					0.21	0.20
		-4	No Noise	MOS			1.9	1.7		
				Confid Interval (+/-)			0.25	0.25		
			30K	MOS	1.0	1.0				
				Confid Interval (+/-)	0.00	0.00				
Technics	Lower	+16	No Noise	MOS	4.6	4.6				
				Confid Interval (+/-)	0.25	0.25				
			30K	MOS					3.5	3.1
				Confid Interval (+/-)					0.38	0.37
		+6	30K	MOS	3.3	3.2				
				Confid Interval (+/-)	0.33	0.30				
		-4	No Noise	MOS			4.2	4.1		
				Confid Interval (+/-)			0.27	0.33		
			30K	MOS			3.8	4.0		
				Confid Interval (+/-)			0.44	0.29		
	Upper	+16	30K	MOS			4.4	3.9		
				Confid Interval (+/-)			0.37	0.32		
			No Noise	MOS			3.9	3.8		
				Confid Interval (+/-)			0.38	0.41		
		+6	30K	MOS					2.1	1.8
				Confid Interval (+/-)					0.31	0.31
		-4	No Noise	MOS			3.7	3.4		

				Confid Interval (+/-)			0.33	0.33		
			30K	MOS	1.5	1.3				
				Confid Interval (+/-)	0.36	0.22				

LAB COMPATIBILITY - MULTIPATH (INDUSTRY EVALUATION)

Urban Fast

	Lower/ Upper	D/U dB	AWGN	Data	Classical No IBOC	Classical IBOC	Rock No IBOC	Rock IBOC	Speech No IBOC	Speech IBOC
Dephi	Lower	+6	00K	MOS	2.6	1.8				
				Confid Interval (+/-)	0.36	0.28				
			30K	MOS			3.7	2.7		
				Confid Interval (+/-)			0.37	0.32		
	Upper	+6	00K	MOS			3.6	3.4		
				Confid Interval (+/-)			0.40	0.34		
			30K	MOS	2.4	1.5				
				Confid Interval (+/-)	0.31	0.25				
Pion	Lower	+6	00K	MOS	3.1	1.6				
				Confid Interval (+/-)	0.30	0.30				
			30K	MOS			3.7	2.6		
				Confid Interval (+/-)			0.40	0.45		
	Upper	+6	00K	MOS			3.3	3.6		
				Confid Interval (+/-)			0.41	0.33		
			30K	MOS	2.6	1.4				
				Confid Interval (+/-)	0.31	0.31				

Urban Slow

	Lower/ Upper	D/U dB	AWGN	Data	Classical No IBOC	Classical IBOC	Rock No IBOC	Rock IBOC	Speech No IBOC	Speech IBOC
Delp	Lower	+6	00k	MOS	2.8	1.9				
				Confid Interval (+/-)	0.42	0.28				
			30K	MOS					2.9	2.2
				Confid Interval (+/-)					0.35	0.33
	Upper	+6	00K	MOS			3.5	3.6		
				Confid Interval (+/-)			0.40	0.42		
			30K	MOS	2.9	2.2				
				Confid Interval (+/-)	0.40	0.37				
Pion	Lower	+6	00K	MOS	3.4	2.0				
				Confid Interval (+/-)	0.25	0.31				
			30K	MOS					2.7	1.7
				Confid Interval (+/-)					0.35	0.31
	Upper	+6	00K	MOS			4.2	3.8		
				Confid Interval (+/-)			0.31	0.45		

			30K	MOS	3.1	2.0		
				Confid Interval (+/-)	0.30	0.40		

Appendix L –
FM IBOC Test Data Report
Table of Contents

NATIONAL
RADIO
SYSTEMS
COMMITTEE

DAB Subcommittee
Evaluation of the iBiquity Digital Corporation IBOC System

Part 1 – FM IBOC

The FM IBOC Test Data Report was submitted to the NRSC electronically, in 27 separate computer files, all in Adobe Acrobat (".pdf") format. Listed below is a description of each file, the number of pages (when printed), and the file size (in kbytes).

Description	# of pages	File size (kbytes)
Main report	56	6438
Appendix A - IBOC FM transmission specification	32	821
Appendix B - Lab test platform	2	65
Appendix C - Lab test procedures for the ATTC	113	558
Appendix D - ATTC summary of test results	65	331
Appendix E - FM field test procedures & notes	44	849
Appendix F.1 - Field test results - WETA	13	2618
Appendix F.2 - Field test results - WPOC	13	953
Appendix F.3 - Field test results - WHFS	17	1803
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Appendix M –
Glossary of terms

NATIONAL
RADIO
SYSTEMS
COMMITTEE

DAB Subcommittee
Evaluation of the iBiquity Digital Corporation IBOC System

Part 1 – FM IBOC

ACR-MOS – Absolute Category Rating Mean Opinion Score. A methodology for subjectively testing audio quality where participants are presented with sound samples, one at a time, and are asked to grade them on a 5 point scale. For the NRSC FM IBOC tests, the MOS scale used was 5=Excellent, 4=Good, 3=Fair, 2=Poor, 1=Bad.

After Market – A radio designed for purchase and installation some time after purchasing an automobile.

All-digital IBOC – The third of three modes in the iBiquity FM IBOC system that increases data capacity by adding additional digital carriers. All-digital IBOC uses four frequency partitions and no analog carrier. In this mode, digital audio data rate can range from 64 kbps to 96 kbps, and the corresponding ancillary data rate will range from 213 kbps for 64 kbps audio to 181 kbps for 96 kbps audio.

ATTC – The Advance Television Technology Center, the prime lab test contractor for the FM IBOC tests.

AWGN – Additive White Gaussian Noise, also known as white noise, which contains equal energy per frequency across the spectrum of the noise employed. In the context of the FM IBOC system tests, AWGN at radio frequencies was utilized in the laboratory tests to simulate the background noise present in the FM spectrum, which affects the quality of radio reception.

Blend to Analog – The point at which the BLER of an FM IBOC receiver falls below some predefined threshold and the digital audio is faded out while simultaneously the analog audio is faded in. This prevents the received audio from simply muting when the digital signal is lost. The receiver audio will also "blend to digital" upon re-acquisition of the digital signal.

Blend to Mono – The process of progressively attenuating the L-R component of a stereo decoded signal as the received RF signal decreases. The net result is a lowering of audible noise.

BLER – Block Error Rate. A ratio of the number of data blocks received with at least one un-correctable bit to the number of blocks received.

Compatibility – When one system has little to no negative impact on another system, it can generally be considered compatible. In the case of this report, compatibility testing has been performed to determine the extent to which the addition of an FM IBOC signal will impact current analog performance.

DAB – Digital Audio Broadcasting.

D/U – Ratio of Desired to Undesired signals (usually expressed in dB).

EWG – Evaluation Working Group of the NRSC DAB Subcommittee

Extended-hybrid IBOC – The second of three modes in the iBiquity FM IBOC system that increases data capacity by adding additional carriers closer to the analog host signal. Extended-hybrid IBOC mode adds two frequency partitions around the analog carrier. In this mode, digital audio data rate can range from 64 kbps to 96 kbps, and the corresponding ancillary data rate will range from 83 kbps for 64 kbps audio to 51 kbps for 96 kbps audio.

Hybrid IBOC – The first of three modes in the iBiquity FM IBOC system that increases data capacity by adding additional carriers closer to the analog host signal. Hybrid IBOC mode adds one frequency partition around the analog carrier and is characterized by the highest possible digital and analog audio quality with a limited amount of ancillary data available to the broadcaster. Digital audio data rate can range from 64 kbps to 96 kbps, and the corresponding ancillary data rate will range from 33 kbps for 64 kbps audio to 1 kbps for 96 kbps audio.

IBOC – In-Band/On-Channel system of digital radio where the digital signals are placed within the current AM and FM bands and within the FCC-assigned channel of a radio station.

Longley-Rice – A model used to predict the long-term median transmission loss over irregular terrain that is applied to predicting signal strength at one or more locations. Longley-Rice computations are employed both by the FCC allocations rules for FM stations to predict signal strength contours and by propagation modeling software to predict signal strengths in a two-dimensional grid on a map. The FCC implementation of Longley-Rice computations employs average terrain computations and an assumed 30-foot receive antenna height. The propagation modeling plots in this report implement Longley-Rice computations with actual terrain data and an assumed receive antenna height of 7 feet.

MPEG-2 AAC – Advanced Audio Coder, a high-quality, low bit rate perceptual audio coding system developed jointly by AT&T, Dolby Laboratories, Fraunhofer IIG, and Sony.

Multipath – An RF reception condition in which a radio signal arriving at a receiving antenna arrives by multiple paths due to reflections of the signal off of various surfaces in the environment. By traveling different distances to the receiver, the reflections arrive with different time delays and signal strengths. When multipath conditions are great enough, analog reception of FM radio broadcasts is affected in a variety of ways, including “stop-light fades,” “picket fencing,” and distortion of the received audio.

NRSC – National Radio Systems Committee, a technical standards setting body of the radio broadcasting industry, co-sponsored by the Consumer Electronics Association (CEA) and the National Association of Broadcasters (NAB).

Objective Testing – Using test equipment to directly measure the performance of a system under test. For example, the power output of a transmitter can be objectively measured using a wattmeter.

OEM – Original Equipment Manufacturer. Generally describes the “factory” radio installed in a car before purchase.

PAC – A flexible high-quality perceptual audio coding system originally developed by Lucent Technologies and later refined by iBiquity. The system can operate over a wide range of bit rates and is capable of supporting multichannel audio.

Perceptual Audio Coding – Also known as audio compression or audio bit rate reduction, this is the process of representing an audio signal with fewer bits while still preserving audio quality. The coding schemes are based on the perceptual characteristics of the human ear. Some examples of these coders are PAC, AAC, MPEG-2, and AC-3.

Protected Contour – A contour is a representation of the theoretical signal strength of a radio station that appears on a map as a closed polygon surrounding the station’s transmitter site. The FCC defines a particular signal strength contour, such as 60 dBuV/m for certain classes of station, as the Protected Contour. In allocating the facilities of other radio stations, the Protected Contour of an existing station may not be overlapped by certain interfering contours of the other stations. The Protected Contour coarsely represents the primary coverage area of a station, within which there is little likelihood that the signals of another station will cause interference with its reception.

RBDS – Radio Broadcast Data System, fully encapsulates the RDS system described below and adds additional features specific to North America such as Emergency Alert System (EAS) and Modified Mobile Broadcast Service (MMBS), a commercial nation-wide paging system.

RDS – Radio Data System, the RDS signal is a low bit rate data stream transmitted on the 57 kHz subcarrier of an FM radio signal. Radio listeners know RDS mostly through its ability to permit RDS radios to display call letters and search for stations based on their programming format. Special traffic announcements can be transmitted to RDS radios, as well as emergency alerts.

SDARS – Satellite Digital Audio Radio Service, describes satellite-delivered digital audio systems such as those from XM Radio and Sirius. The digital audio data rate in these systems is specified as being 64 kbps.

Subjective Testing – Using human subjects to judge the performance of a system. Subjective testing is especially useful when testing systems that include components such as perceptual audio coders. Traditional audio measurement techniques, such as signal-to-noise and distortion measurements, are often not compatible with way perceptual audio coders work and cannot characterize their performance in a manner that can be compared with other coders, or with traditional analog systems.

WQP – Weighted Quasi Peak,